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Weeding out the dealers? The economics of cannabis legalization ☆

Emmanuelle Auriol [a,b], Alice Mesnard [c,*], Tiffanie Perrault [d]

[a] Toulouse School of Economics, Toulouse, France
[b] Centre for Economic Policy and Research, London, United Kingdom
[c] City, University of London, London, United Kingdom
[d] McGill University, Montreal, Quebec, Canada

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ABSTRACT

We model consumer choices for recreational cannabis in a risky environment and its supply under prohibition and legalization. While legalization reduces the profits of illegal providers, it increases cannabis consumption. This trade-off can be overcome by combining legalization with sanctions against the black market, and improvements to the quality of legal products. Numerical calibrations highlight how a policy mix can control the increase in cannabis consumption and throttle the illegal market. In the US, the eviction prices we predict to drive dealers out of business are much lower than the prices of legal cannabis in most of the states that opted for legalization, leaving room for the black market to flourish. Analyzing the compatibility of several policy goals sheds light on the less favorable outcomes of recent legalization reforms and suggests a new way forward.

1. Introduction

Prohibition policies, which target suppliers or consumers of illegal cannabis, are not effective at controlling demand. With 192 million users, cannabis is the most popular illegal recreational drug on earth. It accounts for half of global drug seizures and represents a black market worth 142 billion dollars (UNODC, 2017, 2018). Prohibition has failed to curb consumption and has fueled criminal activities. Drug dealing is the first source of revenue for organized crime and destabilizes the political economy of drug-producing countries while generating criminality in drug-consuming ones. Barro (2003) argues that legalizing and taxing drugs in advanced economies is a more effective way of controlling the drug market than prohibition. Meanwhile, cannabis is less addictive and less deadly than other psychotropic substances.[1] As a result, governments from advanced and developing countries have decided to

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* Corresponding author.
E-mail addresses: emmanuelle.auriol@tse-fr.eu (E. Auriol), alice.mesnard.1@city.ac.uk (A. Mesnard), tiffanie.perrault@mcgill.ca (T. Perrault).

[1] According to a 2017 meta analysis study of more than 10,000 articles, there are no proven serious adverse effects of moderate cannabis use on the health of adults. It is almost impossible to overdose with cannabis (see National Academies of Sciences, Engineering, and Medicine, 2017).

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legalize the recreational use of cannabis. Reforms vary widely from one country/state to the next and reflect different priorities, such as protecting the youth, improving the quality of the products consumed by adults, creating new legal jobs, or raising taxes. However, all reforms share the common goal of reducing criminal activity.

This article investigates theoretically the different ways legalization can be implemented to reach this objective. We explore a legalization policy aimed at strangling the illegal cannabis market through predatory pricing. We examine its impact on several key aspects affecting drug use, including product quality and price, and analyze how defeating crime may conflict with other objectives, such as raising taxes or decreasing consumption. Our analysis highlights a policy trade-off: although a smart legalization reform at predatory pricing may undermine the profits from illegal providers, it also increases cannabis use, which is a sensitive issue politically. In contrast, prohibition decreases cannabis consumption but strengthens the illegal market and fuels criminality. By illuminating this trade-off, our analysis warns policy makers against the unintended consequences of legalization reforms if they neglect the responses of the black market or if they pursue incompatible objectives.

One simple idea advocated by several politicians, notably in Canada, is to sell legal cannabis at a price that competes with the *pre-legalization* black-market price. The analysis shows that this will not be sufficient to eliminate the black market. Prohibition creates barriers to entry, which foster the concentration of the market in the hands of criminal organizations. These networks are able to respond to the legal competition by lowering their price and still make a profit. In this case, cannabis legalization increases consumption of "low-cost" illegal cannabis, with all the negative externalities this entails for society. Furthermore, policy makers have often in the past underestimated consumers' needs and choices. Examples include shortage and low quality of products sold on the legal market following the reforms in Uruguay and Canada, as well as new requirements for getting a medical card and high taxes on recreational products in California. This turned users of cannabis to the illegal market, in contradiction with the initial objectives of the reforms.[2]

After exploring case-studies of recent legalization reforms, we embed their several objectives in a unified framework and analyze their compatibility. Our findings complement the flourishing literature on cannabis legalization. As reviewed in Section 2, this literature is mainly empirical and focuses on the impacts of legalization on specific areas, such as crime, drug use among the young/adult, or public finance. Our paper contributes to the literature by providing a theoretical framework to analyze the highlighted pitfalls, as well as a strategy to avoid them when designing future cannabis legalization policies, which include choosing the price and quality of cannabis sold on the legal market.

We model the demand for cannabis from risk averse individuals in a general framework encompassing both Tversky and Kahneman (1992)'s cumulative prospect theory (CPT) and expected utility theory (EUT), which establishes the robustness of our results. Our use of CPT is consistent with agents' behavior considering risky gambles (for a literature review see Barberis and Thaler, 2003; DellaVigna, 2009; Barberis, 2013).[3] If the sale of cannabis is illegal, consumers weigh the benefits of consumption against the risk and costs of participating in an illegal trade where the price is determined by illegal providers who maximize their profits. To crowd out illegal suppliers, we show that a government must set a low enough price for legal cannabis such that dealers reach their marginal cost if they attempt to keep some customers. They are therefore forced out of the market at this "eviction price". The consequence of this predatory pricing strategy is a sharp increase in cannabis consumption: the demand for cannabis post-legalization is equal to the demand of cannabis that would prevail if the dealers were behaving competitively. This increase in consumption of psychoactive substances resulting from legalization is opposed by a large portion of society and hence problematic politically. To overcome this issue, we examine a policy mix that combines pricing regulation – to limit consumption *post-legalization* – with sanctions against illegal trade – to push criminals out of the market through the sale of legal cannabis. We show that the eviction price for legal cannabis can be adjusted by penalties and marketing tools. In particular, our analysis shows that investment in quality of legal cannabis is an effective instrument for controlling the demand following legalization reforms.

Since legalization reforms have generally multiple objectives, we then embed in our theoretical framework a larger set of policy objectives than drying up the illegal market. We show that prohibition policies are optimal only if a government seeks to minimize total consumption of cannabis and neglects other objectives, such as minimizing the enforcement costs of prohibition. We also show that reducing crime through a regulated market of cannabis sold at the eviction price is compatible with the maximization of consumers' surplus, the minimization of enforcement costs of repression measures, and with the minimization of negative externalities from illegal cannabis consumption. In contrast, the maximization of tax revenues generally leads to the co-existence of legal and illegal markets.

Based on evidence from cannabis markets in the U.S., we next calibrate our model to show its relevance and its usefulness in designing effective legalization policies through counter-factual analysis. Our policy simulations compute eviction prices and the subsequent increases in cannabis use for the US market. In our baseline scenario with a 0.1% probability of arrest and a USD $1,000$ fine for illegal purchase, a legal price around USD 98 per ounce would evict illegal suppliers and increase consumption by 53% to 91%, depending on the elasticity of demand. This is in line with the legalization experiences of Colorado and Oregon, where relatively low prices for legal cannabis – around USD 135 per ounce – diverted consumers from the black market but increased consumption by almost 60%. The policy simulations also highlight the complementarities between the different instruments. For example, not enforcing repression against illegal providers would allow them to compete fiercely and push the eviction price of cannabis down to USD 42, increasing consumption *post-legalization* by 64% to 111%. Interestingly, if a government's objective is

[2] See: Fueller, Thomas. 2019. "Getting Worse, Not Better: Illegal Pot Market Booming in California Despite Legalization". *New-York Times*. April 17. https://www.nytimes.com/2019/04/27/us/marijuana-california-legalization.html.

[3] This theory is the most prominent among non-expected utility theories and provides realistic predictions for individual behavior when confronted to risky choices, both inside (Glöckner and Betsch, 2008; Baltussen et al., 2016) and outside (Barberis et al., 2016; Post et al., 2008) the lab.

to limit the increase in consumption *post-legalization*, the eviction price can be adjusted by improving the quality of legal cannabis relative to illegal products. Doubling consumers' relative valuation of legal products as compared to illegal ones (for example through information campaigns about the dangers of using illegal products, R&D and marketing investments in legal products) would push the eviction price of cannabis up to USD 186, limiting the increase in consumption to range between 37% and 63%. This "quality" channel has been neglected by most authorities, including in Canada and Uruguay. Yet, our simulations show that it is effective to modulate the eviction price and, thereby, to control consumption *post-legalization*.

The rest of the paper is organized as follows. In Section 2 we describe the evolution of the regulation of recreational cannabis markets and review the empirical literature on the impact of legalization measures. In Section 3 we present the set-up of the model, which explains the illegal market structure under *status quo* (prohibition). In Section 4 we analyze how to combine a legal market with measures targeting consumers and suppliers to drive smugglers out of business and regulate cannabis consumption. In Section 5 we enlarge the set of policy objectives to shed more light on current policies. In Section 6 we calibrate the model based on evidence from the U.S. cannabis market and study its policy implications before concluding in Section 7.

2. Legalization of recreational cannabis: an overview of policy impacts

In response to an increase in cannabis use, the seventies were characterized by a wave of decriminalization measures. In the United-States, possessing small amounts (usually up to 1 ounce) of cannabis was declassified to a misdemeanor in eleven states and Alaska declared possession of small amounts of cannabis to be protected under the state constitutional right to privacy (see Appendix A for a chronology of cannabis laws across states in the US). Across the Atlantic, the Netherlands took a bold step by making cannabis available for recreational use in coffee shops. However, the attempts to legalize cannabis more generally stalled with the *War on Drugs* launched by Ronald Reagan in the eighties. Rising concerns about the legitimacy and efficacy of this war led to a second wave of decriminalization and the first laws in favor of medical use in the U.S. at the end of the nineties. This liberalization movement accelerated in the last decade.

In 2012, Uruguay was the first country to legalize recreational cannabis with the aim to counter drug-related crime. The same year, Colorado and Washington states passed bills legalizing recreational use of cannabis, following popular referendums. From 2014 onward, seventeen other states and the District of Columbia followed in the US (see Appendix A), and in 2018, Canada, South Africa and Georgia also changed their legislation in favor of legalizing recreational cannabis. Legalization policies implemented so far are diverse.

In Uruguay, a state monopoly was created. It delegated the production of cannabis to strictly regulated private companies, which led to a sluggish implementation and penury. To eradicate the black market, Uruguay had initially set the price of legal cannabis at the same level as the black market. However, the government's attempt to control consumption led to a severe underestimation of the size of the market and rationing.[4] Thus, several years after legalization, a majority of consumers continue to turn to the black market for their consumption, defeating the initial objective of the reform.

In Colorado and Washington states, the reforms have been market oriented, with a clear focus on consumers' needs and taxation. Ten years after legalization, both states are pleased with these reforms: public finances are thriving and cannabis users have access to abundant and diverse products of quality. In Canada, retail sale of cannabis is legal although the policies vary across provinces, from Québec's government monopoly to Alberta's privately run stores, with mixed results. Section 6 discusses the effects of legalization reforms in North America and their pitfalls in light of our theory.

Based on these examples, the flourishing empirical literature we review below examines the impact of legalization policies on a variety of outcomes.

2.1. Impacts of legalization on crime and violence

The first strand of the literature highlights the costs of drug prohibition, in terms of criminal activities and violence. Resignato (2000) shows that most drug-related violent crimes are the consequence of systemic factors linked to the *War on Drugs* rather than of psycho-pharmacological effects of drug use on crime. Indeed, prohibition increases incentives to engage in criminal behavior (MacCoun and Reuter, 2001). It promotes violence as almost the only way to resolve conflicts and secure market power, encouraging market strategies based on violence (Miron, 1999, 2003). This strengthens the concentration of the market and leads Miron and Zwiebel (1995) to conclude that a free market for drugs would probably outperform prohibition in terms of social costs. The social costs linked to prohibition are exacerbated by "zero-tolerance" policies, which may encourage users to hold higher quantities (Caulkins, 1993).

In line with these arguments, Dills et al. (2017) show that liberalizing cannabis across US states did not lead to a rise in crime. Other evidence by Brinkman and Mok-Lamme (2019) shows that overall crime in Colorado decreased in areas where cannabis dispensaries were added. In particular, cannabis legalization could be responsible for a drop in local rapes and property crimes (Dragone et al., 2019).

[4] By the end of 2017, only two producers were approved for an annual volume of one ton each, while the market has been estimated at between 35 and 40 tons. In addition, the hostility of pharmacists, charged by the state to sell cannabis, has made it more difficult and unpleasant for users to obtain supplies. The authorization of self-cultivation or small producers' clubs, also tightly limited and regulated, has not compensated for the inadequacy of the public supply. See: González, Enric. 2018. "Uruguay loses momentum in the marijuana legalization stakes". *El País*. October 17. https://english.elpais.com/elpais/2018/10/16/inenglish/1539687522_144922.html.

The benefits of legalization policies extend to organized crime. In the states bordering Mexico, legalization of cannabis for medical purposes has decreased drug-trafficking related crime (Morris et al., 2014; Gavrilova et al., 2019; Chang and Jacobson, 2017). Furthermore legalization policies have shrunk criminals' profits, weakening their power. In Italy, a legislative loophole leading to an unintended liberalization of cannabis decreased revenues from cannabis sales on the black market by 90-170 million euros (Carrieri et al., 2019).

2.2. Impacts of legalization on drug consumption

Due to their prohibited nature, illicit drugs are difficult to access and of uncertain quality, adding substantial search costs for consumers (Galenianos et al., 2012). Using a structural approach, Jacobi and Sovinsky (2016) explore the idea that cannabis legalization reduces this cost and removes the stigma attached to illicit consumption. They find that legalizing recreational cannabis would increase its use by around 48%. This is supported by Miller et al. (2017), who use survey data on undergraduate students at Washington State University to show that cannabis legalization induced a rise in consumption early after being implemented. Moreover, the ease of access to licit drugs encourages individuals to start consuming cannabis earlier, as shown in the Netherlands by Palali and van Ours (2015).

Consumers react to the risk of being caught while buying cannabis illegally. Jacobson (2004) shows that lower probabilities to be arrested for cannabis possession increases consumption. So do policy changes involving lower sanctions (as suggested by Pacula et al., 2010), although the size and significance of such effects may vary across different population groups (Williams, 2004). Moreover, experiences of medical and recreational cannabis legalization in the US are correlated with rises in cannabis use. For example, Hunt et al. (2018) find that Marijuana Dispensary Laws in California are associated with a significant increase in driving under influence arrests. In this, cannabis is a normal good, with consumers sensitive to risk and costs variations.

In contrast to adult consumption, legalizing cannabis seems to decrease consumption among the young, provided legal retailers refuse to sell it to underage consumers. DiNardo and Lemieux (2001) do not find any effect of cannabis decriminalization on consumption among high school students, a result confirmed by a recent study in Oregon (Kerr et al., 2017). Furthermore, consumption of cannabis by teenagers is estimated to have decreased by 12% following legalization in the states of Washington and Colorado (SAMHSA, 2014). Finally, legalization does not seem to lead to the feared gateway effect on the use of other psychotropic substance (Dills et al., 2017). On the contrary, cannabis seems to act as a substitute for more powerful and addictive opioids (Powell et al., 2018).

2.3. Legalization and taxation

From a public policy viewpoint, legalization creates a new source of revenue through taxation (Caputo and Ostrom, 1994, 1996). For instance, the state of Colorado collected USD 325.1 million of tax and fee revenue in 2022 and the state of Washington collected USD 515.2 million in the same fiscal year.[5] In the state of Washington, this tax revenue is secured by a substantial degree of market concentration, which results itself from the high taxes set by the authorities (Hollenbeck and Uetake, 2021). Jacobi and Sovinsky (2016) estimate at around USD 12 billion the tax revenue, which could be raised from country-wide cannabis legalization in the US.

Moreover, since consumers are price sensitive – with price elasticities of demand between -0.5 and -0.79 (Davis et al., 2016; van Ours and Williams, 2007) –, a government may use taxes to regulate the increase in cannabis use following legalization. Becker et al. (2006) shows that policies controlling drug use by taxes are more efficient than quantity reductions through prohibition. Taxing cannabis consumption may discourage early initiation into cannabis use by younger users, who are very responsive to low prices (van Ours and Williams, 2007).

This literature review shows that prohibition fuels crime and violence, while stretching law enforcement resources. In contrast, legalization leads to a decrease in overall criminality and generates tax revenue but at the cost of increasing cannabis consumption. By their empirical focus the papers reviewed cannot explain these results in a comprehensive way. They are limited by data availability and focus on specific geographic areas and topics (e.g. violence, youth consumption, public finance). They miss some aspects of the market. For instance, none of the papers address consumer welfare and quality issues. Having a more comprehensive view of the implications of legalizing recreational cannabis is important for policymakers before embarking on such a controversial reform. We complement this literature by studying the theory behind the policy trade-offs.

3. Prohibition equilibrium

We start our analysis by studying the illegal market under prohibition. In the absence of a legal option, consumers can only purchase illegal cannabis from dealers. We describe the demand and supply sides of the illegal market, which determine the price in equilibrium.

[5] See Washington State Treasurer (https://www.tre.wa.gov/portfolio-item/washington-state-marijuana-revenues-and-health/) and Colorado Department of Revenue (https://cdor.colorado.gov/data-and-reports/marijuana-data/marijuana-tax-reports), retrieved online on March 3, 2022.

3.1. Demand under prohibition

Potential customers for illegal cannabis are heterogeneous. They have different "tastes" for the commodity, θ, which are drawn from the distribution $G(\theta)$, twice differentiable, with support $\mathbb{R}$ and density function g.

Individuals who like cannabis are characterized by a positive θ, and those who dislike it, by a negative one. When the illegal cannabis is of quality $v > 0$, its value for individual θ is given by θv. In other words, cannabis is vertically differentiated (i.e., a higher v corresponds to a better quality cannabis). This assumption is an improvement over the existing literature, in which cannabis is generally modeled as a uniform product.

Under prohibition, consumers who purchase black-market cannabis at the unit price p are subject to a probability $q \in [0, 1]$ of being caught by the police. If caught, they lose the benefit of the commodity, the price paid for it, p, and faces a legal punishment $F \geq 0$ (e.g. fine, prison term). The net payoff of a consumer caught by the police while purchasing illegally is $-p - F$; while the net payoff for an individual who is not caught is $\theta v - p$. Accordingly, we model the decision to consume cannabis illegally as a lottery $\mathcal{L}_{\text{illegal}} = [-p - F, \theta v - p; q, 1 - q]$. For an individual of taste $\theta \in \mathbb{R}$, the lottery has an expected value of

$$w^{+}(1-q)u(\theta v - p) + w^{-}(q)u(-p - F), \tag{1}$$

where the utility function u is continuous, strictly increasing in $x \in \mathbb{R}$ and such that $u(0) = 0$,[6] while the probability weighting functions w^{+} and w^{-} are increasing in $x \in [0, 1]$, so that $w^{+}(0) = w^{-}(0) = 0$ and $w^{+}(1) = w^{-}(1) = 1$.

This framework is general. It encompasses the standard expected utility approach by setting $w^{+}(1-q) = 1 - q$ and $w^{-}(q) = q$ and considering an increasing, concave utility function (e.g., CARA). It also encompasses Tversky and Kahneman (1992)'s cumulative prospect theory (CPT), where attitudes towards risk are reference-dependent, probability weighting functions are not linear and the value function u is S-shaped, with an inflection point at zero.[7]

The consumer, who is indifferent between illegal consumption and no consumption, is characterized by the taste θ^{I}, solution to the following equation:

$$w^{+}(1-q)u(\theta^{I} v - p) + w^{-}(q)u(-p - F) = 0 \tag{2}$$

Any consumer of type $\theta \geq \theta^{I}$ purchases illegal cannabis, while consumer of type $\theta < \theta^{I}$ does not. We show in Appendix B that, under our assumptions, $\theta^{I} > 0$ exists and is unique.

The demand for the illegal commodity can thus be written as:

$$D^{I}(p) = \int_{\theta^{I}}^{+\infty} g(\theta) d\theta = 1 - G(\theta^{I}) \tag{3}$$

The following comparative statics results regarding the marginal consumer and the price elasticity of demand for illegal cannabis are derived in Appendix B.

First, θ^{I} increases with p so that a higher price reduces the demand, illustrating that cannabis is a normal good. However, this is not a policy instrument under prohibition, since the equilibrium price on the illegal market results from interactions between unregulated (and untaxed) criminals. Second, θ^{I} increases with q: the demand for the illegal commodity decreases with the probability of arrest, which is the desired effect of prohibition policies. It discourages individuals from purchasing illegally, which leads to a more positive selection of consumers (i.e. a larger θ^{I}).

Finally, our framework establishes that, for taste distributions $G(\theta)$ satisfying the monotone hazard rate (MHR) property,[8] the (absolute value of the) price elasticity of demand,

$$\epsilon_{D^{I},p} = \frac{-D^{I\prime}(p)p}{D^{I}(p)} = \frac{\mathrm{d}\theta^{I}}{\mathrm{d}p} \frac{g(\theta^{I})}{1 - G(\theta^{I})} p, \tag{4}$$

increases with the risk of being caught $q \in [0, 1]$.

3.2. Cannabis supply under prohibition

We model the oligopolistic market for the illegal supply of cannabis as a generalized Cournot competition, with initially a fixed number $N \geq 1$ of criminal networks operating. This model allows us to incorporate some market power and to circumvent the Bertrand paradox without burdening the model with features such as capacity constraints, first mover advantage or horizontal product differentiation (in addition to the vertical product differentiation already present). Since the paper does not rely on any implication of a Cournot competition other than the oligopoly-induced market power, this assumption is innocuous.

We focus on the retail market for cannabis. We assume that black-market suppliers are subject to symmetrical cost functions: $C(q_i) = cq_i + K$ where $K \geq 0$ is the sunk fixed cost to set up the illegal network and $c \geq 0$ is the constant marginal cost of supplying

[6] This normalization reflects that losses lead to a negative value and gains lead to a positive value.

[7] While expected utility theories focus on final wealth, CPT models variations in outcome from a given *status quo*. The S-shaped value function allows for diminishing sensitivity and loss aversion. In other words, it accounts for the facts that "*perceptions are a concave function of the magnitudes of change*" and that "*people dislike losses significantly more than they like gains*" (Rabin, 1998).

[8] The monotone hazard rate (MHR) property is satisfied by most usual distributions.

the commodity. Each of the N suppliers competes by simultaneously determining the quantities q_i they offer. The market price p^N is determined by the inverse demand function $p(Q)$, where $Q = \sum_{i=1}^{N} q_i$. Each supplier $i = 1, ..., N$ chooses the quantity $q_i \geq 0$ maximizing their profit, $q_i p(q_i + q_{-i}) - C(q_i)$, where $q_{-i} \equiv Q - q_i$. The first order condition of this problem determines their reaction function:

$$q_i = -\frac{p(q_i + q_{-i}) - c}{p'(q_i + q_{-i})} \tag{5}$$

Since, at equilibrium, each of the N suppliers best-responds to the others, and since their cost functions are symmetrical, the right-hand side of equation (5) is the same for all $i = 1, ..., N$. Each dealer supplies the same quantity $q_i = \frac{Q}{N}$ and the generalized Cournot price p^N with $N \geq 1$ smugglers is implicitly defined by the following equation (see Carlton and Perloff, 2015, , chapter 6)[9]:

$$\frac{p^N - c}{p^N} = \frac{1}{N} \frac{1}{\epsilon_{D^I,p}} \tag{6}$$

where $\epsilon_{D^I,p}$ is the price elasticity of demand defined in (4). It is easy to check that, all else being equal, the price in (6) is increasing in the marginal cost of production, c, an intuitive result, and decreasing in N: the higher the number of competing providers the lower their mark-up. The generalized Cournot competition price is between two extreme cases: $c \leq p^N \leq p^m$ for all $N \geq 1$ where $p^m \equiv p^1$ in the monopoly case and $p^\infty = c$ in the competitive case when $N \to \infty$.

We have established in Appendix B that the price elasticity of demand, $\epsilon_{D^I,p}$, increases with q. Using (6) we deduce that the oligopolistic price is lower when the risk q increases. Risk-aversion implies that the price charged by smugglers is lower than the price they would impose on risk-neutral individuals with the same expected payoff from consumption.[10] Dealers must compensate risk-averse consumers for the risk involved in purchasing illegal cannabis.

Finally, for ease of exposition, we assume that N is initially fixed, as it is in the short run. However, in a more dynamic setting when the government opens the market to legal substitutes, we can endogenize N. We focus on a free entry equilibrium where dealers enter the market when their expected profit is positive and exit the market when their variable profit is negative. The asymmetry between entry and exit decisions reflects the fact that the fixed cost of setting up an illegal cannabis production and distribution network, K, is sunk. Once the drug dealers have paid it, there is no way to recoup K by exiting the market. The decision to exit the market is therefore based on the variable profit, $\pi(N) = (p^N - c)\frac{D^I(p^N)}{N}$. When $\pi(N) < 0$, we assume that some dealers exit the market until their number $N' \in \{0...N\}$ is such that $\pi(N') \geq 0$. By contrast, there is entry of a new dealer when $\pi(N+1) > K$. The maximal number of criminal organizations N that can operate profitably is the integer part of n such that $\pi(n) = K$, where $\pi(n) = (p^n - c)\frac{D^I(p^n)}{n}$ is the firm variable rent. Therefore, any repressive measure increasing c or K reduces the number of criminal networks active on the market and increases the price they charge (see equation (6)).

4. Legalization policies

This section studies the effect of legalization policies on the cannabis market equilibrium. We model legalization as a game led by the government which is a Stackelberg leader. The black-market retailers react to the actions of the government. Their payoffs are determined in the final stage by consumers' decisions who choose between legal and illegal products when both are supplied on the market. The timing of the game, solved by backward induction, is described below.

4.1. Timing of the legalization game

1. The government sets up the legal retail market for cannabis and the level of repression on the black market to maximize its objective function, which is eradicating the drug-dealers in Section 4.4 and a compound of several policy objectives (consumer surplus, revenue from excise taxes, negative externalities generated by the legal and illegal sectors, policy enforcement costs) in Section 5.
   (a) It determines the price of the legal cannabis $p^L = (1+\tau)c^L$, where c^L is the marginal cost of producing the commodity legally, by setting the level of excise tax τ.[11]
   (b) It chooses whether to boost the "quality differential" $b \geq 1$ between legal and illegal products, of quality bv and v respectively. The parameter b captures the fact that, unlike illegal products, legal products are certified and their potency and composition, including pesticide and other chemicals, are known to consumers at the time of purchase.[12] Moreover, purchasing legally alleviates search costs and personal cost in terms of ethics and social stigma. Finally, the purchase experience is usually better in a shop than on the street.

[9] Since $q_i = \frac{Q}{N}$, equation (5) becomes $\frac{Q}{N} = -\frac{p(Q)-c}{p'(Q)}$, equivalent to $\frac{p(Q)-c}{p(Q)} = -\frac{1}{N}\frac{Qp'(Q)}{p(Q)}$ which yields (6).

[10] Dealers face different types of consumers. If they can identify them, they may apply different prices. As is standard with third degree price discrimination, groups with the largest price elasticity get the smallest price. In contrast, captive consumers (i.e., groups with low price elasticity) are charged higher prices.

[11] The government chooses the final price p^L paid by consumers through the tax rate. Cannabis is an easy to grow agricultural product, highly adaptable to various climatic conditions. When the government encourages competition among the growers and the retailers, they do not make any rent. It can then modulate the final price by imposing an excise tax τ (e.g. as is widely done for the retail of tobacco). More generally, the government may influence the concentration of the legal market by artificially raising its cost of entry (e.g. limiting the number of licenses). Our results extend easily to an oligopoly setting, in which the Cournot price when legal retailers compete among themselves, net of taxes, is proportional to the marginal cost and the share of the sector rent captured by the government is simply smaller.

[12] Quality certification under legalization usually involves regulating cropping techniques; in particular the use of pesticides, which are shown to be harmful for health (Subritzky et al., 2017). So, in general, for the same type of product (e.g., loose cannabis of a given strain), quality is better in the legal sector.

(c) It sets the level of enforcement of repression against consumers and producers of illegal cannabis, $e = (q, \delta)$. It influences on the demand side the probability of arrest q, and on the supply side, the increase in marginal cost to produce illegally due to repression, $\delta \geq 0$, such that $c = (1+\delta)c^L$. In addition, it could, at least in theory, influence the level of fine F. In practice, fines are very constrained by the legal framework, determined more by the "punishment proportionality" principle than by any other consideration such as cost-effectiveness. Overinflated fines may also be too costly to enforce and congest the judiciary system. This is why we take the maximum possible fine, F, as given in our analysis.

2. The dealers respond to the government's legalization policy. In the absence of certification norms on the black market, dealers have no way to credibly signal quality to consumers.[13] Hence, they cannot adjust the quality of their product. They can only adjust their prices to maximize the profit

$$\Pi\left(p, p^L | b\right) = (p - c)\, D^I\left(p, p^L | b\right)$$

where $D^I\left(p, p^L | b\right)$ denotes the residual demand for black-market cannabis. If this variable profit is negative, dealers exit the market, until either the variable profit with the new number of drug-dealers N' is positive or there is none left to serve the illegal market. Should the illegal retailers exit the market, their payoff is zero. They share equally the variable profit otherwise.

3. The final payoffs of both parties are determined by the market outcomes, as consumers decide whether to consume or not, and on which market. Depending on the relative prices of legal and illegal products and the quality differential, the black market survives or is eradicated.

4.2. *The demand for legal and illegal cannabis*

Turning to the final stage of the game, this section studies consumption decisions following the implementation of a market for legal cannabis of quality b, sold at price p^L, given that dealers sell illegal products at price p.

We present in the main text the analysis under the assumption that consumers behave according to prospect theory. However all our results hold whether we model consumers' behavior under expected utility theory or prospect theory, as shown in Appendix C and Appendix D. Only the way the marginal consumer is derived under legalization differs slightly. In prospect theory, the marginal type, $\theta^L(p, p^L)$, indifferent between legal and illegal consumption, is the solution of[14]:

$$w^+(1-q)u\left(p^L - p - \theta v(b-1)\right) + w^-(q)u\left(p^L - p - \theta b v - F\right) = 0, \tag{7}$$

while, if individuals are expected utility maximizers, the marginal consumer is the solution of: $(1-q)u(\theta v - p) + qu(-p - F) = u\left(\theta b v - p^L\right)$. For example, with a CARA utility function $\theta^L(p, p^L)$ is such that $(1-q)u\left(p^L - p - \theta v(b-1)\right) + qu\left(p^L - p - \theta b v - F\right) = 1$, which is similar to (7) but not equal. Appendix C shows that in both cases (EUT and CPT) there is a range of legal prices such that $\theta^L(p, p^L)$, increasing in p^L and decreasing in p, exists and is unique. Any individual above this threshold prefers to purchase legally rather than illegally, and symmetrically for those below the threshold.

Finally to determine the demand for legal cannabis we also need to consider the threshold θ^0, above which consumers prefer to consume legal cannabis at price p^L rather than not consuming at all[15]:

$$\theta^0(p^L) = \frac{p^L}{bv} \tag{8}$$

Following the implementation of a legal market for cannabis sold at price p^L, when the price on the illegal market is p, two cases may occur (as formally shown in Appendix D.1).

- The legal price is set low enough: $p^L \leq \tilde{p}^L(p) = \theta^I b v$. The legalization has the intended effect of drying up the illegal cannabis market: $\theta^L \leq \theta^0 \leq \theta^I$.[16] In this case, illustrated in Fig. 1, $\int_{\theta^0}^{\theta^I} g(\theta)\mathrm{d}\theta$ new cannabis consumers appear.
- The legal price is too high to totally undermine the dealers: $p^L > \tilde{p}^L(p) = \theta^I b v$. The illegal cannabis market survives: $\theta^I < \theta^0 < \theta^L$. In this case, if the illegal providers maintained the same price as under prohibition, the overall demand for cannabis would not change. The high-type segment of the former black market, consumers with valuation above θ^L, would switch to the legal market as shown in Fig. 2. Under legalization, individuals with a high valuation for cannabis turn to the legal market and pay attention to quality, while they neglect it under prohibition where products are not certified. The residual demand for illegal cannabis would become:

$$D^I(p, p^L) = \int_{\theta^I(p)}^{\theta^L(p,p^L)} g(\theta) d\theta. \tag{9}$$

[13] Besides, illegal retailers are likely to be subject to sticky contracts upstream, since most transactions on the black market happen between individuals who are already acquainted (Caulkins and Pacula, 2006).

[14] In prospect theory individuals deciding between legal and illegal consumption take the certain payoff associated with the legal option, $\theta b v - p^L$, as reference. Concretely they make their decision by subtracting the certain payoff from their payoffs when they purchase illegally. Engaging in illegal consumption is then modeled as a lottery $[p^L - p - \theta b v - F, p^L - p - \theta(b-1)v; q, 1-q]$ which yields (7).

[15] That is, it is such that $u(\theta b v - p^L) = 0$.

[16] Recall that θ^I defined in (2) is the threshold above which an individual prefers to make an illegal purchase rather than no purchase at all. When $p^L \leq \tilde{p}^L(p)$, θ^I becomes higher than θ^L, the threshold above which an individual prefers to buy legally rather than illegally: the illegal market disappears.

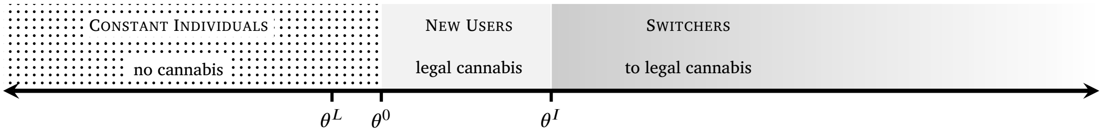


Fig. 1. Change in consumer choices *post-legalization* when $p^L \leq \tilde{p}^L(p)$.

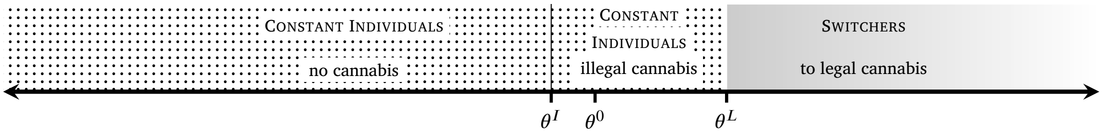
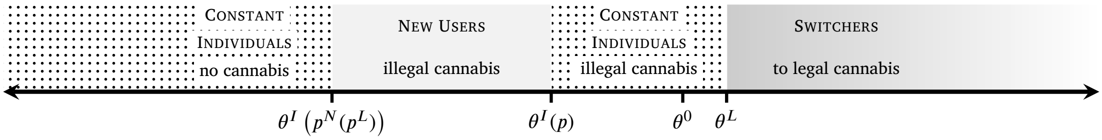


Fig. 2. Change in consumer choices *post-legalization* when $p^L > \tilde{p}^L(p)$.



Note: p is the price of cannabis on the black market under prohibition and $p^N(p^L)$ its price following legalization.

Fig. 3. Change in consumers choice *post-legalization* when $p^L > \tilde{p}^L(p)$ and illegal providers push down their price in response to legalization.

4.3. Response of illegal providers

To keep some consumers and maximize their profits, illegal providers adjust their price in stage 2. The price $p^N(p^L)$ – of illegal cannabis following legalization – is the result of the Stackelberg competition between the legal and the illegal providers on one hand, as well as the competition within the illegal market on the other hand. Formally, the price reaction function of the smugglers is the solution of the following equation:

$$p(p^L) = \begin{cases} p^N(p^L) & \text{if } \ c \leq p^N(p^L) < \frac{p^L}{b} \\ \emptyset & \text{otherwise} \end{cases} \tag{10}$$

where $p^N(p^L)$ is the solution of (6) computed with $\epsilon_{D^I,p} = -\frac{\partial D^I(p,p^L)}{\partial p}\frac{p}{D^I(p,p^L)}$, the direct price elasticity of the demand $D^I(p,p^L)$ defined in (9).

Rewriting (6) as $p^N = c\left(1 + \frac{1}{N\epsilon_{D^I,p} - 1}\right)$ shows that the reaction price is increasing in c and decreasing in N. Besides, as shown in Appendix C.3, $\epsilon_{D^I,p}$ decreases with p^L and hence p^N increases with p^L. This allows us to establish the following lemma.

Lemma. *As long as the illegal providers are active, i.e. have positive margins, their reaction price is increasing in their marginal operating costs, c, and in the price on the legal market, p^L; and is decreasing in the number of active criminal networks in the market, N.*

Facing competition from the legal market on the high bound of the consumer distribution, illegal providers push down their prices. However, they need to make a positive margin to continue their operations. If the value for money of black-market cannabis is sufficiently attractive relative to legal cannabis, the black market survives: $\theta^I\left(p^N(p^L)\right) < \theta^L$. The illegal providers have the ability to compete with the provision of legal cannabis and attract consumers in the middle bound of the taste distribution by pushing down their price $p^N(p^L)$ – and still make a profit. The resulting demand for legal and illegal cannabis is illustrated in Fig. 3. Because the price-response of the black market pushes down $\theta^I\left(p^N(p^L)\right)$, the total number of consumers of (legal and illegal) cannabis increases *post-legalization*.

Otherwise, if the price of legal cannabis, p^L, is set at a sufficiently low level, the drug-dealers exit the cannabis market, some consumers of illegal cannabis switch to legal cannabis and, in addition, new users appear. Two situations may typically lead to this configuration: (i) the dealers' marginal cost of operations, c, is too high relative to the price they need to charge to retain some customers, pushing them out of the market; or (ii) the price value for legal cannabis is high – i.e. its quality b is high compared to its price p^L – so that consumers switch to legal cannabis, drying up the demand for illegal products.[17]

We deduce the next proposition.

Proposition 1. *Once a legal market is implemented, if the costs of operating on the black market and the repression against illegal purchases are held constant, for any level of quality differential,* $b \geq 1$*, the overall demand for cannabis increases.*

Proof. See Appendix D.2.

In other words, cannabis consumption increases *post-legalization*. This has been observed everywhere that cannabis has been legalized so far. Proposition 1 thus highlights a policy trade-off: policy makers have to choose between controlling cannabis consumption with the help of dealers regulating the illegal market (the *status-quo* in many countries), or implementing a legal market, which necessarily increases consumption.

In the past, several policy makers with the goal of eradicating the illegal market have used the intuitive approach of matching the price of legal cannabis to the black-market price: $p^L = p$. Our analysis explains why this policy leads to significant increases in consumption. For a given price, the value of consuming legal cannabis is higher ($b > 1$) and there is no risk of being sanctioned ($q = 0$), such that the demand for cannabis increases: $\theta^0(p) < \theta^I(p)\ \forall p > 0$.[18] Further, such price setting strategy ignores the fact that dealers may lower their price to keep some customers, as analyzed above: in addition to increasing consumption, this policy does not necessarily eradicate crime.

This is illustrated by the legalization experience in Québec, where the *Société Québécoise du Cannabis (SQDC)*, a subsidiary of the provincial society for alcohols, provides cannabis both in shops and online. Dried flower products were initially priced between CAD 8 and 10 per gram by the SQDC, depending on potency and strain type, which was close to the *pre-legalization* black-market price.[19] This pricing policy promoted by the Minister of Public Health at the time, Lucie Charlebois, to annihilate illegal consumption did not anticipate the response of dealers. The black market survived by lowering prices. In mid March 2019, the crowd-sourced website www.priceofweed.com reported the average black-market price in Québec having fallen below CAD 6 per gram. As a result, cannabis consumption increased among adults.[20]

4.4. Eradicating the illegal market through eviction pricing

Since legalization reforms all share the goal to eradicate crime, we now consider a price setting strategy for the legal supply which destroys economic incentives for dealers to operate. The strategy is such that the price of dealers is pushed below their marginal costs after they respond to the policy. Let $\theta^I(p)$ be defined in (2). We deduce the next proposition.

Proposition 2. *To drive illegal suppliers out of business, the legal price of cannabis should be set below the eviction price* $\underline{p}^L = bv\theta^I(c)$*, which, without additional measures, yields the same level of consumption as under perfect competition among illegal suppliers:* $D^L(\underline{p}^L) = D^I(c)$.

Proof. See Appendix E.1.

This result is general. Irrespective of the way we model consumers' behavior (i.e. expected utility or prospect theory) and the initial market conditions (i.e. monopolist, oligopolistic or competitive), if the government wants to drive out illegal providers, it has to apply a price lower than the threshold price $\underline{p}^L = bv\theta^I(c)$, which is such that their mark-up vanishes after they respond to the policy. We refer to the price $\underline{p}^L$ as the *eviction price*.

Since $\theta^I(c)v - c > 0$ it follows that $\underline{p}^L > c$: the eviction price of legal cannabis is higher than illegal providers' marginal cost, c. Nevertheless, since legal cannabis is of better quality and its purchase involves no risk, the demand at this eviction price, which is now legal, is at the same level as if illegal suppliers were pricing their products on the illegal market at marginal cost.

As compared to the status-quo situation of an oligopolistic illegal market, such an increase in drug consumption following legalization may not be desirable for the society, nor politically sustainable. In fact, to date, not a single politician proponent of legalization has disputed this. They highlight the benefits of legalization in eradicating crime but seem to assume that consumption will remain the same after legalization. This assumption has led in the past to a serious underestimation of demand after legalization, as for example in Canada and Uruguay, and thus to the rationing of cannabis users who have turned to the black market. On the other hand, if the increase in cannabis consumption is anticipated, this will prompt opposition to legalization by many citizens, health

[17] When c and/or b are high it becomes more difficult for criminals to push down their price and meet the constraint $c \leq p^N(p^L) < \frac{p^L}{b}$.

[18] Since θ^I increases with the risk q, we deduce that: $\theta^I(p) > \theta^I_{q=0}(p) = \frac{p}{v} \geq \theta^0(p) = \frac{p}{bv}$, $\forall b \geq 1$ and $q > 0$.

[19] See "Environ '7-8 dollars le gramme' pour du pot légal" by Martin Croteau in *La Presse*, Sep. 21 2017. https://www.lapresse.ca/actualites/politique/politique-quebecoise/201709/21/01-5135353-environ-7-8-dollars-le-gramme-pour-du-pot-legal.php.

[20] The statistical bureau of Quebec (*Institut de la Statistique du Québec*) reported that the proportion of cannabis users aged 15 and over increased from 14% to nearly 20% between 2018 and 2021 in Québec. In particular, 26% of the 25- to 34-year-old reported to have consumed cannabis in the year prior to 2018; while they were 36% in 2021. See: Institut de la Statistique du Québec. Oct.15 2021. https://statistique.quebec.ca/en/communique/augmentation-consommation-cannabis-plus-25-ans-mais-diminution-15-17-ans-en.

workers and anti-drug associations. Policy makers need more sophisticated tools to regulate the demand for cannabis *post-legalization*. Our theoretical framework shows that the price that drives criminals out of business can be adjusted.

Corollary. *The eviction price* $\underline{p}^L$ *increases with the marginal costs of illegal providers* c*, the probability of arrest of their consumers* q*, the associated fine amount* F*, and the quality differential between legal and illegal cannabis* b*.*

Proof. See Appendix E.2

Intuitively, additional measures affecting c, q, F and b make competing with the legal provision of cannabis more difficult for illegal providers. Combining these four instruments helps contain the increase in cannabis consumption following legalization: their economic activities can be throttled more easily such that the eviction price can be set higher. This is either because consumers have higher relative expected payoffs if they consume legally, or because illegal providers operate with increased costs. This dampens the increase in demand following legalization. The optimal combination of these instruments is discussed with the policy objectives in the next section.

5. Enlarging the set of policy objectives

So far we have focused on policies that try to eliminate the black market through eviction pricing. Yet governments pursue a larger set of objectives when they implement legalization policies. These include reducing the negative externalities for health – especially large for the youngest users (i.e. teenagers) – and for societies generated by the consumption of psychoactive substances, redeploying police forces and relieving congestion in courts and prisons to reduce enforcement costs, increasing consumer surplus while controlling the quality of products and developing a sector that generates legal activities and new tax revenues. Although current reforms share most of these objectives, they may have different priorities. In this section, we model a (utilitarian) government's objective function as a linear combination of these objectives and study their interactions with the crime eradication objective.

Recall that $e = (\delta, q)$. The government maximizes its objectives as follows:

$$\begin{aligned} &\max W^G(e,b,\tau) \\ &\quad \equiv \alpha_T T(e,b,\tau) - \alpha_C C(e,b,\tau) + \alpha_S S^c(e,b,\tau) - \alpha_\xi \xi(e,b,\tau) \end{aligned} \tag{11}$$

where $\alpha_T \geq 0$, $\alpha_C \geq 0$, $\alpha_S \geq 0$, $\alpha_\xi \geq 0$ are the weights attached to each objective in the utilitarian welfare function and where

- $T(e,b,\tau) = \tau c^L D^L\left(p,(1+\tau)c^L|b\right)$ is the revenue from excise taxes on legal cannabis.
- $C(e,b,\tau) = E(\delta,q) - qD^I\left(p,(1+\tau)c^L|b\right)F$ corresponds to the enforcement cost, $E(\delta,q)$, increasing and convex in δ and q, net of the fines.
- $S^c(e,b,\tau) = S^L(p,(1+\tau)c^L|b) + S^I(p,(1+\tau)c^L|b) - \Psi(b)$ is the sum of the consumer surpluses on the legal and illegal markets, net of $\Psi(b)$, the cost of legal cannabis quality improvement, which is strictly increasing and convex.
  - The net consumer surplus on the legal market is $S^L\left(p,(1+\tau)c^L|b\right) = \int_{(1+\tau)c^L}^{\infty} D^L(p,t|b)\mathrm{d}t$.
  - The net consumer surplus on the illegal market is $S^I\left(p,(1+\tau)c^L|b\right) = (1-q)\int_p^{\bar{p}^I} D^I\left(t,(1+\tau)c^L|b\right)\mathrm{d}t - qD^I\left(p,(1+\tau)c^L|b\right)F$, with $\bar{p}^I$ being the choke-off price on the illegal market.
- $\xi(e,b,\tau) = \xi_I D^I\left(p,(1+\tau)c^L|b\right) + \xi_L D^L\left(p,(1+\tau)c^L|b\right)$, with $\xi_I \geq 0$ and $\xi_L \geq 0$, is the negative externalities generated by the illegal and legal sectors, which are increasing in their respective demands.

We consider in turn four different objectives that can be decentralized through the choice of enforcement of sanctions against the illegal sector, $e = (q, \delta)$, and regulation of the legal sector (b, τ), and study whether they are compatible with the goal of deflating organized crime by setting an eviction price for legal cannabis. We show that the objectives sometimes reinforce each other, while in other cases they are conflicting. This offers an explanation as to why some reforms have been disappointing in the past.

Minimizing negative externalities: $\alpha_T = \alpha_S = \alpha_C = 0$ *and* $\alpha_\xi > 0$

Because both legal and illegal consumption of psychotropic substances entail health hazards, a government focusing on such externalities minimizes $\xi(e,b,\tau) = \xi_I D^I\left(p,(1+\tau)c^L|b\right) + \xi_L D^L\left(p,(1+\tau)c^L|b\right)$. We need to distinguish two cases.

- $\xi_I \leq \xi_L$: when legal use of cannabis is perceived as having larger negative externalities than illegal use then the government will choose prohibition. Only in this case does the government minimize total consumption. All else being equal (i.e. for the same investment level in repression) legalization inevitably leads to an increase in demand as shown in Section 4. Therefore, for a given repression budget, prohibition is the policy that minimizes total consumption of cannabis. To limit the demand for (illegal) cannabis, the government should invest in repression. It should increase the repression against users (i.e. q) to decrease the number of people willing to purchase the illegal substance (i.e. to increase θ^I in (3)). Similarly, increasing the sunk costs and the marginal cost of producing illegally pushes the number of illegal providers N down and their prices up, as shown in Section 3. The highest price and lowest demand is achieved by a criminal monopolist.

- $\xi_I > \xi_L$: in contrast, a government may consider that illegal cannabis is more harmful than legal cannabis for several reasons. The quality of legal products can be certified and health damages reduced. Illegal cannabis can be sold to minors or vulnerable groups, who are at risk of developing psychosis. The ban of sale to the under-aged cannot be enforced on the black market: criminals do not mind who is buying their products, as long as they get paid. Finally, it generates a whole range of criminal activities, including violence, corruption and money laundering (see Section 2).
Clearly if $\xi_L = 0$, the legalization below eviction price $\underline{p}^L = bv\theta^I(c)$ derived in Proposition 2 is optimal. Indeed if consumers derive utility from cannabis consumption without incurring, nor generating, any negative externality, then reducing its use is a cost, not a benefit. Certain practices, such as driving or working under the influence, should still clearly be prohibited but should be targeted through a different kind of selective policies.[21] Now if $\xi_L > 0$, the government seeks to annihilate illegal consumption while controlling legal demand, which is achieved through a policy mix described in the corollary to Proposition 2.

This leaves open the question of how much the government should invest in the repression against the dealers and their customers. We study this question next.

Optimizing net enforcement cost: $\alpha_C > 0$

The net enforcement cost of repression, $C(e, b, \tau) = E(\delta, q) - qD^I(p,\ (1+\tau)c^L|b)\,F$ is strictly positive because, in practice, $qD^I\left(p, (1+\tau)c^L|b\right)F$, the revenue from arrests, is always lower than the gross cost of enforcement, $E(\delta, q)$. A government concerned about the cost of the war on drugs might try to optimize the use of law enforcement instruments. We consider two cases.

- Minimizing net enforcement cost: $\alpha_T = \alpha_S = \alpha_\xi = 0$ or $\alpha_\xi > 0$ and $\xi_I > \xi_L = 0$.
In these two cases the government wants to minimize the burden for tax payers of the net enforcement cost of repression, $C(e, b, \tau) = E(\delta, q) - qD^I\left(p, (1+\tau)c^L|b\right)F$, without restricting consumption. The solution consists in implementing the eviction price $\underline{p}^L = bv\theta^I(c)$. The government avoids investing too much in repression (q and δ should be minimal) as it is costly. It implies that $\theta^I(c)$ in (3) will be low in equilibrium. It also implies that the level of taxes will have to be relatively low at $\tau^{\alpha_C} = \frac{bv\theta^I(c)}{c^L} - 1 > 0$ since $v\theta^I(c) > c \geq c^L$.[22] In other words, minimizing the cost of enforcement in a regulated cannabis market is best achieved by implementing a relatively low eviction price, which means that the subsequent increase in demand for cannabis is large.
- Implementing the eviction price under a demand target: $\bar{D}$
A government concerned by the increase in consumption following the legalization at the eviction price, as would typically be the case when $\xi_I > \xi_L > 0$, may try to minimize the net enforcement cost, while containing consumption. It then aims to minimize $C(e) = E(\delta, q)$ subject to $D^L(\underline{p}^L) \leq \bar{D}$ with $\underline{p}^L = bv\theta^I((1+\delta)c^L)$ being the eviction price defined in Proposition 2. This case yields the following proposition describing the cost-effective combination of instruments required to limit the consumption of legal cannabis post-legalization.

Proposition 3. *To eradicate the illegal market while containing the (legal) use of cannabis to a level $\bar{D}$, the cost-effective combination of policy instruments is such that the consumption constraint is binding, $D^L(\underline{p}^L) = \bar{D}$, and:*

$$\frac{\frac{\partial D^L\left(\underline{p}^L\right)}{\partial q}}{\frac{\partial D^L\left(\underline{p}^L\right)}{\partial \delta}} = \frac{\frac{\partial E(\delta,q)}{\partial q}}{\frac{\partial E(\delta,q)}{\partial \delta}} \tag{12}$$

Proof. See Appendix F.1.

Equation (12) is a standard result: to optimize the utilization of inputs (here law enforcement resources) the marginal rate of transformation between q and δ in terms of reduction of demand (LHS) should be equal to their relative marginal cost (RHS).

- Minimizing net enforcement cost under a demand target $\bar{D}$: $\alpha_C > 0$ and $\alpha_\xi > 0$
If $\xi_I \leq \xi_L$, then the government objective is to minimize the net enforcement cost of repression $C(e, b, \tau) = E(\delta, q) - qD^I\left(p, (1+\tau)c^L|b\right)F$ subject to $D^I\left(p, (1+\tau)c^L|b\right) \leq \bar{D}$. This is typically the objective of most prohibitionist governments. Since reducing the illegal demand is only made possible by further – costly – investments, for a given level of fine F, the constraint is binding: $D^I\left(p, (1+\tau)c^L|b\right) = \bar{D}$ and the optimal levels of q and δ then satisfy:

[21] We are grateful to Jeffrey Miron for suggesting this discussion.

[22] Applying the eviction price $\underline{p}^L$, the corresponding level of taxes τ^{α_C} is simply given by: $bv\theta^I(c) = (1+\tau^{\alpha_C})c^L \Leftrightarrow \tau^{\alpha_C} = \frac{bv\theta^I(c)}{c^L} - 1$. Note that $\tau^{\alpha_C} > 0$. Indeed, $c = (1+\delta)c^L$ and, by definition, $\theta^I(c)$ satisfies $w^+(1-q)u(\theta^I(c)v - c) + w^-(q)u(-c-F) = 0$, such that $v\theta^I(c) > c \geq c^L$.

$$\frac{\frac{\partial D^I(p,(1+\tau)c^L|b)}{\partial q}}{\frac{\partial D^I(p,(1+\tau)c^L|b)}{\partial \delta}} = \frac{\frac{\partial E(\delta,q)}{\partial q} - F\bar{D}}{\frac{\partial E(\delta,q)}{\partial \delta}} \tag{13}$$

Compared to equation (12), the demand in the left-hand side of (13) is the demand under prohibition and on the right-hand side there is the additional term $-F\bar{D}$. It disappears in (12) because when the regulator chooses legalization at eviction price the black market does not survive and there is no fine collected. Interestingly, under prohibition, everything else being equal, increasing q is more cost effective than increasing δ as the government collects fines when users are arrested. In theory, fixing a very large value for F is a cheap way to control demand. Yet, very high fines are not feasible in practice. First they would violate the proportionality requirement of punishment (buying cannabis is not a serious crime). Second, as most individuals caught would not be able to pay them, this would result in – costly – congestion of the judicial system. This is why we consider it as given and fixed at its maximum level F, as discussed in Section 4.1.

Finally the way repression is targeted and enforced matters too. For the sake of simplicity, we abstract from the fine tuning of repression policies by focusing on vertically integrated drug dealers. Yet, unpacking the vertical relationship between traffickers and retailers yields interesting and subtle insights (Poret, 2002, 2009). The effects of stricter drug law enforcement policies, depending on whether they target retailers or traffickers, have different effects on wholesale and retail prices of drugs. Poret (2002) hence shows that ill targeted efforts to increase repression can, by disrupting well organized drug cartels, decrease final users' prices and increase consumption.

Maximizing consumer surplus: $\alpha_T = \alpha_\xi = \alpha_C = 0$ *and* $\alpha_S > 0$

We consider the case of a government aiming at maximizing consumer surplus $S^c(e, b, \tau) = S^L(p, (1+\tau)c^L|b) + S^I(p, (1+\tau)c^L|b) - \Psi(b)$. Legal cannabis is a superior good compared to illegal cannabis. First, the quality of legal cannabis is better, and second, the purchase experience involves no risk. It implies that when they are sold at the same price all consumers prefer legal cannabis to illegal cannabis. The consumer willingness to pay for legal cannabis is higher than the consumer willingness to pay for illegal cannabis. Moreover, costs of supplying legal cannabis are lower than costs of illegal cannabis. Hence, for a given quantity, the consumer surplus is the highest when only legal cannabis is exchanged. A government prioritizing consumer surplus will therefore choose a legalization policy such that the illegal market does not survive (see these conditions in case 1, Appendix F.2). In other words, a government focusing on consumer surplus should choose a price lower than the eviction price. If the government has the sole objective of maximizing the consumer surplus, it should set the price of legal cannabis as low as feasible, and not tax legal cannabis, i.e. set $\tau = 0$ and $p^L = c^L$. The government should also aim to improve the quality of cannabis products (notably in terms of variety, availability, marketing and packaging) to increase $S^L(p, (1+\tau)c^L|b)$ while taking into account the costs of this investment, $\Psi(b)$. That is, the government maximizes with respect to b the function $\int_{(1+\tau)c^L}^{\infty} D^L(t|b)\,\mathrm{d}t - \Psi(b)$. The next proposition derives the optimal investment level.

Proposition 4. *To maximize consumer surplus a government should invest in quality* b^* *such that:*

$$\int_{(1+\tau)c^L}^{\infty} \frac{\partial D^L(t|b)}{\partial b}\mathrm{d}t = \Psi'(b). \tag{14}$$

The quality investment, b^*, that maximizes consumer surplus equalizes the marginal surplus of consumers with the marginal cost of quality improvement. This aspect of legalization reforms is generally neglected by policy makers. It is rarely discussed in public debates or by the media. Because cannabis is perceived as a sinful product, it is not treated like other consumption goods, for which quality is a central issue for consumers, producers and regulators. This is unfortunate because selling legal products of better quality facilitates the eviction of the illegal cannabis market, while increasing the surplus of consumers of legal products.

Maximizing tax revenue: $\alpha_S = \alpha_\xi = \alpha_C = 0$ *and* $\alpha_T > 0$

Some governments have the objective to substantially increase their tax revenue when they legalize recreational cannabis. This objective is for instance at the heart of the legalization reforms in California. When focusing on tax revenue, the government will choose $\tau^{\alpha_T} > 0$ such that $\frac{\partial T}{\partial \tau} = 0$, assuming an interior solution exists. We deduce the next proposition.

Proposition 5. *To maximize tax revenues a government should choose the excise tax level* $\tau^{\alpha_T} > 0$ *such that:*

$$1 - G(\theta^l) = \tau c^L g(\theta^l)\frac{\partial \theta^l}{\partial p^L}, \tag{15}$$

with $\theta^l = \theta^0 = \frac{p^L}{bv}$ *if the black market has been eliminated, and* $\theta^l = \theta^L$ *defined in (7) if not.*

Proof. See Appendix F.2

Note that the black market may survive or not depending on the level of tax, the level of repression on both the demand and supply sides of the cannabis market and the quality differential. In Appendix F.2, we develop an example where θ follows an exponential distribution on the positive real line so that we can derive closed form solutions. This simple example highlights that the unconstrained solution (i.e., in the absence of competition by the black market) leads to a larger excise tax than the constrained solution: $\tau_0^{\alpha_T} \geq \tau^{\alpha_T}$,[23] which is intuitive. When the government does not have to deal with competition it can impose higher taxes, as the consumers are captive. Unsurprisingly, the price resulting from the tax optimization problem is generally higher than the eviction price $\underline{p}^L = bv\theta^I((1+\delta)c^L)$. There is a trade-off between maximizing tax revenue and crime eradication.

The flourishing opium market at the beginning of the 19th century illustrates this trade-off. To control the opium market in the East-Indies, the Dutch government imposed a state monopoly and provided licences to consumers in what was called *opium regie*. Although the aim was to regulate the market and tax it better, it had to compromise between imposing low prices (getting lower revenues) and having fewer smugglers on the market, or getting higher revenues with a high regulated price, which allowed smugglers to enter the market and compete on price (van Ours, 1995).

A way to limit the problem of black-market resurgence is to encourage investment by legal producers and distributors in quality of their products. A higher quality gap b between the legal and illegal market increases the eviction price and implies a lower increase in *post-legalization* demand or the possibility to implement higher tax rates, without fueling the illegal market. For instance, if the goal is to maximize tax revenue, investment in quality, b_τ, should be set so that: $\tau c^L \frac{\partial D^L(p,(1+\tau)c^L/b)}{\partial b} = \Psi'(b)$. At the optimum, the marginal benefit in terms of tax collection of the quality improvement is equal to its marginal cost. Nevertheless, when the government aims at maximizing tax revenues, and neglects to encourage R&D investments to improve quality, or to substantially increase sanctions against dealers, part of the black market will survive. We explore whether this is indeed likely to be the case in practice in Section 6.

Discussion of the compatibility of reforms' objectives

This review of legalization objectives shows that deflating crime through an eviction price is compatible with the maximization of consumer surplus, the minimization of enforcement cost related to the regulation of cannabis market, and the minimization of negative externalities entailed by illegal cannabis use. Interestingly enough, justifying prohibition based on our general economic framework requires that public authorities consider health hazards and other negative externalities entailed by legal cannabis consumption equal or worse than those entailed by illegal cannabis. The current dominant policies of prohibition are only optimal when the government wishes to minimize the total consumption of cannabis regardless of its source.

Moreover, we have shown that for legalization reforms to succeed at eradicating crime, the quantity and quality of legal cannabis, as well as the relative value of the purchasing experience for legal versus illegal products must be high. An important and generally overlooked tool the government can use to regulate the cannabis market post-legalization is to improve the quality of legal cannabis relative to illegal cannabis. To fight the black market, an abundant provision of products of good quality is key. This effort should be increased as governments put more weight on health externalities, consumer surplus, enforcement cost or tax revenue.

Finally, the analysis suggests that the maximization of tax revenue may conflict with the eradication of the black market. For many values of the model parameters, without substantial reinforcement of repression against illegal activities or quality improvements of legal products, the objective of maximizing tax revenue leads to higher final prices of legal cannabis than eviction prices. This leaves room for illegal providers to operate. Whether this is likely to happen in practice, following legalization reforms, is explored in the following section.

6. Policy implications

In this section we calibrate eviction prices based on data from the US market and explore corresponding variations in cannabis consumption *post-legalization* depending on how policy instruments – investments in repression of illegal activities and in quality of legal cannabis – are combined. We then use these calibrations to examine whether maximizing tax revenue may lead policy makers to set retail prices of legal cannabis higher than eviction prices, which by itself explains the survival of black market. Finally, comparing our model's predictions to case-studies, we offer explanations for why past legalization reforms in some states of the U.S. have been disappointing.

The calibration exercise uses the CPT functional forms derived by Tversky and Kahneman (1992) detailed in Appendix G. In particular, they assume that individuals are risk-averse for gains, risk-seeking for losses and that "*losses loom larger than gains*" (Kahneman and Tversky, 1979). These features of consumers' attitude towards risk are modeled using the following value function:

$$u(x) = \begin{cases} x^\alpha \text{ , if } x > 0 \\ -\lambda(-x)^\alpha \text{ , if } x \leq 0 \end{cases} \tag{16}$$

[23] They are equal only when $q = 1$.

with $\alpha \in (0,1)$ and $\lambda \geq 1$ measuring the degree of loss aversion. Further, they allow for individuals to have a poor ability to assess probabilities, by overestimating the odds of rare salient events, and underestimating the odds of more common events. These distortions reflect cognitive biases in criminal behavior as individuals commonly overestimate the typically low risk of being arrested (Chalfin and McCrary, 2017). Individuals' distorted perceptions of positive (respectively negative) outcomes are modeled by the probability weights w^+ (respectively w^-), where:

$$w^x(q) = \frac{q^{\gamma^x}}{\left(q^{\gamma^x} + (1-q)^{\gamma^x}\right)^{\frac{1}{\gamma^x}}} \qquad \text{with } x = +, -. \tag{17}$$

Using these specifications and our model, the eviction price $\underline{p}^L = bv\theta^I(c)$ takes the following closed-form expression shown in Appendix G:

$$\underline{p}^L = b\left[\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} (F+c) + c\right], \tag{18}$$

6.1. Benchmark parameters

The exogenous parameters calibrated by Tversky and Kahneman (1992) are $\lambda = 2.25$, $\alpha = 0.88$, $\gamma^+ = 0.61$ and $\gamma^- = 0.69$.[24] We benchmark the policy parameters F, q, c, and b based on studies of the US market.

We use the maximum fine of the federal law, set at USD 1,000 for cannabis possession on a first offense, as a benchmark, given it is applied in a non-negligible number of states.[25] Since fines vary across states, we perform a sensitivity analysis on a range of realistic values.

Nguyen and Reuter (2012) highlight that the average probability of being arrested in possession of cannabis where it is prohibited is around 1% although sex, age, and ethnicity strongly influence the probability of being stopped by the police. Following the legalization of recreational cannabis, illegal users are more difficult to detect, which is why we set the benchmark value for the probability of arrest at $q = 0.1\%$ *post-legalization* and perform a sensitivity analysis using a large range of values for this policy parameter. This includes a 0 probability of being arrested to reflect lax enforcement against the consumers of illegal cannabis.

Although production costs of operation by illegal providers are hard to estimate precisely, we choose USD 50 per ounce as our benchmark value.[26] This cost increases strongly with sanctions against black market suppliers, who may incur large losses and have to constantly adapt their activities. This motivates our sensitivity analysis using a large range of values.

The extent to which individuals value more highly the use of legal cannabis relatively to illegal one, b, is also difficult to measure. It reflects not only some product attributes in terms of chemical composition (e.g. potency, taste), but also in their quality standards, both at upstream (cropping and processing) and retail (shopping experience) levels. We set the benchmark measure of b using the relative THC potency of legal and illegal cannabis. Taking the potency or purity as a measure of quality is relatively standard in the literature on markets for illicit drugs (see for instance Galenianos et al., 2012; Galenianos and Gavazza, 2017). According to ElSohly et al. (2016), the average THC potency of cannabis seized in the US in 2014 was 11.84%, while around the same time, the THC potency on Colorado's legal market was 18.7%, yielding $b = \frac{18.7}{11.84} \approx 1.58$ as a benchmark.[27] The fact that consumers consider legal cannabis superior to illegal cannabis is also in line with experimental findings on the substitutability of legal and illegal cannabis in catchment areas where the two types of products are available (Amlung et al., 2019). Our sensitivity analysis uses a large range of values for the parameter b, which strongly depends on public policies as well. It includes values below 1, reflecting poor quality of products as initially experienced by consumers in Canada following the legalization reform.

6.2. Eviction price of cannabis and demand increase following legalization

We first use the benchmark values and specifications discussed above to calibrate the eviction price on the U.S. cannabis market given in (18). We obtain a price for legal cannabis at around USD 97.79 per ounce. Then we compute the increase in demand following the legalization at eviction price. This requires an estimate of the price elasticity of demand of cannabis. Based on the estimates of van Ours and Williams (2007) between -0.50 and -0.70 and of Davis et al. (2016) between -0.67 and -0.79, our calibrations allow for a range of price elasticities of demand between -0.5 and -0.8. Assuming that the taste for cannabis θ is normally distributed, we calibrate in Appendix H.1 the parameters of the Gaussian distribution using our model and the literature on cannabis demand.[28] We find predicted increases in demand in the range of 53% to 92%, depending on the price elasticity of demand adopted.

[24] The (weak) sensitivity of the distribution parameters and of the predictions of the models to the behavioral parameters γ^+, γ^-, α and λ is discussed in Appendix H.2.

[25] Fines for any amount seized, on a first offense, are described at: https://norml.org/laws/federal-penalties-2/.

[26] The LSE Expert Group on the Economics of Drug Policy (Quah et al., 2014) estimates the wholesale price of a pound of illegal cannabis under prohibition to be around USD 3,500, and about 10 times smaller under legalization – which is consistent with Caulkins (2010). The LSE Expert Group also reports the typical farmgate price quoted in the media to be around USD 2,000 per pound (i.e. USD 125 per ounce). Accordingly, the marginal cost for an ounce of illegal cannabis *post-legalization* ranges between USD 25 and USD 125.

[27] Briggs, Bill. 2015 "Colorado Marijuana Study Finds Legal Weed Contains Potent THC Levels". *CNBC News*, March 23. .

[28] Appendix H.1 shows that the mean value of θ varies between -436.4 and -1090.9 when the elasticity varies between -0.8 and -0.5. This negative average "taste" parameter for cannabis is consistent with surveys in the US reporting negative attitudes towards cannabis consumption on average.

Table 1
Legal markets across the U.S.

State	p	p^L	Recreational retailers	McDonald's restaurants	Share of US legal market	Population
AK	298.24	361.57	123	32	0.63%	0.7
CA	256.57	344.45	901	1,279	34.9%	39.5
CO	241.75	143.07	587	209	15.1%	5.6
MA	339.68	354.25	113	170	4.2%	6.9
NV	270.57	295.54	70	134	2.6%	3.0
OR	210.39	127.06	661	130	7.7%	4.2
WA	233.73	198.45	512	167	12.8%	7.5

Prices are in USD per ounce, as of fall 2018. The legal price for Washington State is extrapolated from Lang Jones, Jeanne and Rob Smith. 2019. "Tight Regulations, High Taxes May Keep Washington State's $1.4B Cannabis Industry from Really Blooming". *Seattle Business*. January. https://web.archive.org/web/20190716223415/https://seattlebusinessmag.com/policy/tight-regulations-high-taxes-may-keep-washington-states-14b-cannabis-industry-really-blooming (accessible through the Internet Archive Wayback Machine). All other legal prices are state averages quoted from New Frontier Data (2019), while state average black-market prices are retrieved from the crowd-sourced website www.priceofweed.com, which was accessed using the Internet archive Wayback Machine. Numbers of retailers and testing facilities are retrieved from New Frontier Data's "Cannabis Legalized States" interactive map, as of July 2020. The number of McDonald's restaurants in each state is scraped from Google Places, as of August 2020. Shares of the US legal market are projections quoted from New Frontier Data (2017). Population is expressed in million inhabitants, as of 2018.

For comparison, we present in Table 1 the illegal and legal prices, p and p^L respectively, observed in 7 states of the U.S. in 2018. We also report the number of licensed recreational retailers, and, for comparison, the number of McDonald's restaurants, as well as each state's share of the U.S. legal market for cannabis. These figures give an idea of the degree of liberalization of the market for recreational cannabis in each state, which we discuss with the legalization reforms below.

In most states, the predicted eviction price for legal cannabis is much lower than the observed legal prices, which helps explaining why the black market is thriving, especially in California. But in the case of Colorado and Oregon prices of legal cannabis are closer to the eviction price, which explains why, in these two states, cannabis consumers have massively shifted toward the legal market.[29] The research firm New Frontier Data (NFD) estimates Oregon's legal market share at 86% in 2020, just behind its share in Colorado, at 87% (New Frontier Data, 2020). In the same report, NFD forecasts that by 2025, 93% of cannabis demand in Oregon will be met with legal products.

This shift toward legal cannabis was accompanied by a bump in overall demand: the National Survey on Drug Use and Health reports cannabis prevalence in Oregon to have increased by almost 60% between 2014 and 2017. Colorado saw a similar evolution of its demand between 2012 and 2015, having preceded Oregon in its legalization reform.[30] These figures are consistent with increases in demand predicted by our model to be in the range of 53% to 92%. The evolution of the cannabis markets in Oregon and in Colorado illustrates the relevance of Proposition 2, which predicts substantial increases in cannabis consumption when legalization is implemented at a price close to eviction price.

6.3. *Effects of policies on post-legalization equilibrium*

We now turn to studying how the eviction price can be adjusted depending on the enforcement of other policy instruments and how this affects predicted variations in cannabis consumption following legalization reforms. This counter-factual exercise allows us to see which instruments are the most effective depending on the objectives of the reform. Fig. 4 represents eviction prices as a function of the black-market marginal cost c on the x-axis and the quality differential b on the y-axis. Yellow zones represent low prices – below USD 50 per ounce – while dark zones represent high prices – above USD 400 per ounce. To each level of eviction price represented on the color scale "Eviction price $\underline{p}^L$" we associate the "Corresponding demand variation $\Delta D(\underline{p}^L)$", which is the predicted percentage variation in demand *post-legalization* as compared to the level under *status-quo* for a price elasticity of -0.8.[31] For example, at our benchmark eviction price (very close to USD 100 per ounce) the demand nearly doubles if the price elasticity is -0.8. When the eviction price is around USD 415 per ounce, because investments in repression and in quality are very large, the demand remains constant *post-legalization*. Appendix H.3 presents some robustness analysis for three other values of price elasticity, -0.7, -0.6 and -0.5 in the range supported by the evidence discussed above.

[29] Oregon commission reports from 2019 and 2021 demonstrate that the state of Oregon, where legal prices are the lowest and where licences have been flourishing, has been successful in "[offering] the illicit market steep competition" (Oregon Liquor Control Commission, 2021).

[30] The NSDUH bases these estimates of prevalence of cannabis use upon the extensive margin of consumption over a 12-month period, for a population aged over 12. In Colorado, the estimated prevalence was 10.41% in 2011-2012 and 16.57% in 2014-2015. In Oregon, it was 12.38% in 2013-2014, 12.73% in 2014-2015 and 19.23% in 2016-2017. These figures were retrieved online using the Substance Abuse and Mental Health Data Archive public data analysis system (https://pdas.samhsa.gov/saes/state).

[31] In line with the theory of rational addiction (Becker and Murphy, 1988), individuals are more sensitive to price variations of addictive goods in the long run than in the short run (see Becker et al., 2017, for empirical evidence). Further, demand for legal cannabis is more price elastic (see Hollenbeck and Uetake, 2021), than for illegal cannabis, whose elasticity estimates are in the range we discuss above.

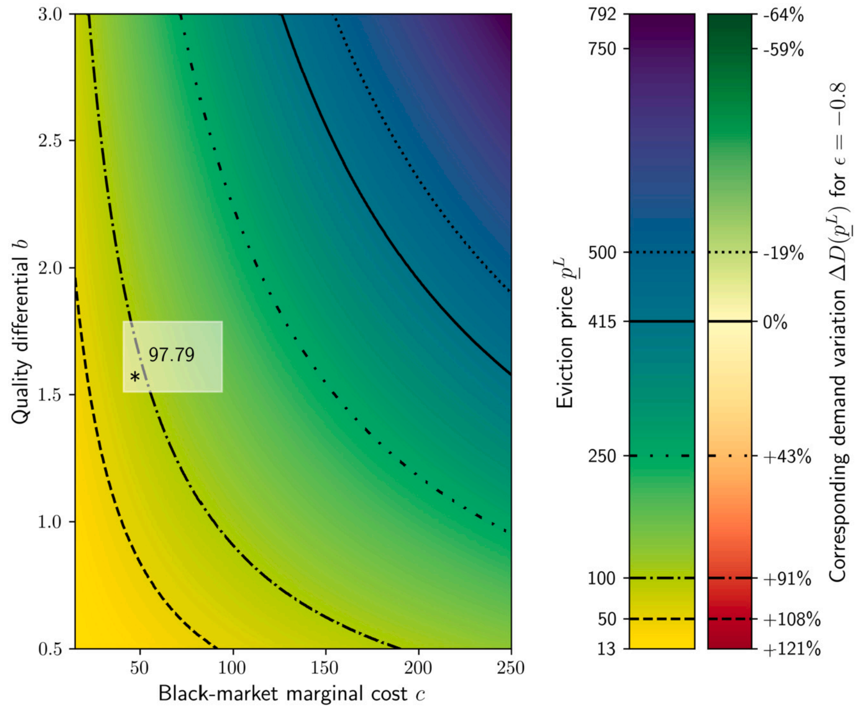


Fig. 4. Eviction price $\underline{p}^L$ as a function of the black-market marginal cost c and the quality differential b. Notes: Prices are in USD per ounce. All the eviction prices represented on this figure are computed with the fine amount F being fixed at USD 1,000 and the probability of arrest after legalization being fixed at $q = 0.1\%$, as well as the benchmark values for the model parameters, $\alpha = 0.88$, $\lambda = 2.25$, $\gamma^+ = 0.61$ and $\gamma^- = 0.69$. The point represented by an asterisk is the benchmark eviction price of USD 97.79, which is computed from the values of the policy parameters, $c = 50$ and $b = 1.58$. The different lines represent the following isoquants: $\underline{p}^L = 50$ (dashed), $\underline{p}^L = 100$ (dash-dotted), $\underline{p}^L = 250$ (dashed double-dotted), $\underline{p}^L = 415$ (solid) and $\underline{p}^L = 500$ (dotted). (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

Our results show that the post-legalization equilibrium responds substantially to each policy parameter. Yet some may appear less costly to change than others. An intuitive idea to increase the eviction price $\underline{p}^L$, at seemingly low costs, would be to increase the fine F. For example, with a USD 5000 fine for illegal purchase and other parameters set at their benchmark values then a legal price around USD 169 per ounce would evict illegal providers and contain the increase in consumption.[32] However, this ignores the hidden costs discussed earlier such as the crowding of the judicial system and the punishment proportionality principle. For similar reasons, it is costly to enforce arrests of users of illegal recreational cannabis after cannabis has been legalized.[33]

More promising are policies enforcing sanctions against illegal providers, instead of consumers. Our simulations show that marginal costs of production for illegal providers, c, play a large role in the control of cannabis consumption *post-legalization*. For example, not enforcing repression against them would entail low production costs at around USD 15 per ounce and push the eviction price of cannabis down to USD 42, which would more than double the demand following legalization as illustrated in Fig. 4.[34] We conclude that maintaining pressure on criminal networks is key to the success of any legalization reform, as it allows to control consumption of psychoactive substance *post-legalization*. This illustrates that legalization and repression (i.e., sanctions against illicit activities) are complementary policies.

Finally, the sensitivity analysis highlights the potential for investing to increase b, the perceived difference between the quality of legal and illegal cannabis. From a policy perspective it may seem counter-intuitive to invest in quality control and marketing of legal cannabis to limit the increase in *post-legalization* demand, especially when a large fraction of the population is opposed to the legalization. Yet, the eviction price strongly increases with b, which allows policy makers to mitigate the increase in consumption *post-legalization*. For example, doubling b from 1.58 to 3 pushes the eviction price of cannabis up to USD 186, limiting the increase in consumption substantially.[35] Although this channel is effective at tilting consumption towards the legal sector and controlling it, efforts to improve and advertise the quality of legal products have been generally neglected by public authorities. This partly explains

[32] Depending on the price elasticity of demand, the increase ranges between 40% and 68%, see Table H.8.

[33] Putting aside these constraints, enforcing the probability of arrest to remain at the prohibition level – that is around $q = 1\%$ – would entail an increase in the eviction price of legal cannabis to USD 197 per ounce, limiting the increase in consumption following legalization. Depending on the price elasticity of demand, the increase ranges between 35% and 60%, see Table H.8.

[34] Depending on the price elasticity of demand, the increase ranges between 64% and 111%, see Table H.8.

[35] Depending on the price elasticity of demand the increase ranges between 37% to 63%, see Table H.8.

some countries' disappointing experience with past reforms. It has also been largely overlooked by researchers in economics. To our knowledge we are the first to look into this aspect of cannabis legalization policies.

The policy scenarios discussed so far only affected one parameter at a time. In practice, these measures can be combined, which, with convex cost functions, is more cost-effective as discussed in Section 5.[36] Different examples and a discussion of the sensitivity analysis of eviction price and *post-legalization* consumption to combined measures can be found in Table H.9 in Appendix H.3. Both sets of results highlight that, unless a government significantly invests in the quality of legal products or strongly re-enforces controls against the illegal market, the eviction price is around USD 100 or below. This leads to substantial increases in cannabis use following its legalization.

6.4. Policies maximizing tax revenues

This section uses our framework to predict prices on the legal and illegal markets when the government focuses on maximizing tax revenues. In addition to the benchmark values discussed above, we use a value for the marginal costs to produce in the legal sector set at USD 25 in line with Quah et al. (2014) and Caulkins (2010). Methodological detail, as well as simulations for different scenarios in terms of investment into enforcement and quality, can be found in Appendix I.

The results highlight that, in most policy scenarios, the price on the legal market maximizing the tax revenue from legal sales is much higher than the eviction price. For example, for the benchmark policy parameters presented in the first row of Table I.10, the price maximizing tax revenue is roughly USD 297 per ounce. This is consistent with Hollenbeck and Uetake (2021) who argue that the state of Washington is on the ascending portion of the Laffer curve, with a legal price for cannabis around 200 USD per ounce (see Table 1). Since the price of legal cannabis that maximizes tax revenues is generally much higher than the eviction price (i.e. USD 97.79 per ounce for the benchmark scenario), the black market survives. Depending on the policy scenario, the black market may account for 15% to up to 44% of the market. This is supported by evidence showing that the black-market represents 15% to 50% of the transactions in the state of Washington (Arcview Market Research and BDS Analytics, 2019). All these results are robust to scenarios where consumers are less price responsive, as illustrated in Tables I.11 to I.13. As a result, increases in cannabis consumption *post-reforms* maximizing tax revenue are lower than if a legalization reform is implemented at eviction price.

Interestingly, when the quality of cannabis sold on the legal market is not different from the illegal market, the legal price that maximizes tax revenue is relatively close to the eviction price and very little black market survives. This shows a case where maximizing tax revenue and eradicating the black market are compatible. However, with a legal cannabis of low quality, the level of tax revenue is low. Tables I.14 to I.17 show that these results are robust to a setting with lax controls, in which, post legalization, consumers are not arrested for illegal purchases ($q = 0$).[37]

6.5. Lessons from legalization reforms in North America

Following citizens' initiative referendums in November 2012, Colorado and Washington State legalized the recreational use of cannabis. The reforms gave priority to reducing the costs of prohibition, developing a new sector of activity, and generating tax revenue.[38] Since the initial goal was to meet consumers' needs, production, distribution and sale were entrusted to private operators, who invested in market-driven R&D and quality development. A legal industrial sector has since developed: as of today, each of these states accounts nearly three times more recreational cannabis retailers than McDonald's restaurants (see Table 1). This booming legal market generates a substantial revenue, with a market size estimated at around USD 1 billion in 2016 in each of these states (for a population of 5.6 million in Colorado and 7.4 million in Washington State). In Washington State, where the final price is close to USD 200 per ounce, the level of taxes is high, as are quality requirements. This explains why the black market still represents 15% to 50% of the cannabis transactions (Arcview Market Research and BDS Analytics, 2019).[39] Nevertheless, a few years after legalization, both states are quite happy with the impact of the reforms on their local finances and economy and adult consumers enjoy a great variety of high quality cannabis products. These two states had a clear set of compatible priorities that were achieved by combining a market orientation for customers with relatively high taxation.

In contrast, California encounters difficulties to meet one of the main objectives of its legalization reform, raising tax revenue. In an environment where the Medical Marijuana Laws had made the gray economy prosperous, the introduction price/quality ratio of the legal cannabis was too high compared to the price/quality ratio on the illegal market. Since the cannabis industry was already well established under prohibition, consistently with our predictions, it reacted swiftly to the legal offer by lowering its prices. It has since grown, absorbing customers who previously were purchasing medical cannabis legally. Illicit transactions account for approximately 80% of the Californian cannabis market. As a result, tax revenue from the legal sector is a fraction of what was

[36] For instance if the probability of arrest goes up to 0.5% *post-legalization* and fines are set to USD 4,000, a quality differential of 2 enables to set the eviction price at USD 422, which maintains consumption at the prohibition level.

[37] Our simulations in Appendix I show for example that when the probability of arrest is zero and $b = 1.01$, the tax maximizing price is similar to the eviction price.

[38] The *Colorado Marijuana Legalization Amendment,* or *Amendment 64*, claims that cannabis legalization is *"in the interest of the efficient use of law enforcement resources, enhancing revenue for public purposes, and individual freedom"*.

[39] According to New Frontier Data economist Beau Whitney, quoted by: Lang Jones, Jeanne and Rob Smith. 2019. "Tight Regulations, High Taxes May Keep Washington State's $1.4B Cannabis Industry from Really Blooming". *Seattle Business*. January. https://web.archive.org/web/20190716223415/https://seattlebusinessmag.com/policy/tight-regulations-high-taxes-may-keep-washington-states-14b-cannabis-industry-really-blooming (accessible through the Internet Archive Wayback Machine).

expected and the government of the state is quite disappointed by the reform.[40] A better policy would have been to fix a lower introduction price of legal cannabis (i.e., lower tax rate, at least initially), combined with investments to raise quality and marketing to give a competitive edge to the legal products, and a stronger push back against illegal cannabis producers and consumers, in line with the policy mix we discuss in Section 5.

The priorities of the recent legalization reform in the state of New York are markedly different from earlier reforms in the US.[41] Presented as a social measure, one of its main objectives was to put an end to severe repression disproportionately affecting minorities. The relatively low point of sale retail tax rate – a 9% state tax combined with a 4% local tax – suggests that the state black market is likely to be eradicated quickly.[42] It is expected to generate a tax revenue of USD 350 million *per annum* as well as to create 30,000 to 60,000 jobs.

In Canada, the federal government gave to the provinces the responsibility of implementing the new policy by regulating the retail markets, as well as setting possession, use, and cultivation limits for personal use.[43] The effects of cannabis legalization in Canada on the black market are difficult to assess. Using monetary circulation, Goodhart and Ashworth (2019) show that the need for cash decreased in the country shortly after the legalization, which they interpret as a decrease in black-market cannabis transactions. For them, the country is heading towards one of the goals Trudeau had set in 2015: "[keeping] profits out of the hands of criminals".[44] However, this optimism is contradicted by the evolution of the market. The striking shortages at the early hours of legalization, as witnessed in Québec,[45] led legal providers to focus on increasing their supply, with no effort to improve the quality of their products, nor the purchasing experience of the consumers (resulting in a low b). As a result, a thriving black market was still satisfying the demand of over 40% of Canadians in the third quarter of 2019.[46] The black market has survived by lowering its prices, which is consistent with the theory, and the stock market prices of the new legal firms have plummeted.[47] The overall (legal plus illegal) demand for cannabis has increased in Canada, with the extensive margin of use rising from 22% in 2018 to 27% in 2022.[48]

With the objectives of eradicating the black market and drug-related crime, Canada made the same mistake as Uruguay: the failure to anticipate the reaction of the black market to legalization and to internalize consumers' demand for quantity and quality led to poorly designed reforms, at least initially.[49]

7. Conclusion

By modeling the decisions of cannabis consumers in a risky environment and the behavior of black-market suppliers *pre*- and *post-legalization*, we lay out a general framework to reflect on existing legalization reforms and design optimal policies. We show that when legalization is not combined with enforcement of sanctions against illegal activities, it necessarily entails an increase in cannabis use. Past and current legalization reforms illustrate the complexity of designing legalization policies. Situations in which cannabis is legal but too expensive (e.g., California) or rationed and of low quality (e.g., Uruguay or Canada) have resulted in flourishing illegal businesses with no significant decrease in crime. Our analysis shows how to avoid these unexpected effects. We characterize the *eviction* price for legal cannabis and show how this predatory price can be embedded in a policy mix, such that the government can "weed the dealers out" of the market while curbing the – legal –demand for cannabis by raising its price.

Our findings highlight the complementarities between legalization of high quality cannabis (in terms of purchasing experience, gustatory quality of the product, potency and purity) and sanctions against illegal trade, providing policymakers with guidelines to overcome the legalization/consumption increase trade-off. Legalization will be effective at regulating the demand for cannabis if consumers are compelled to buy on a legal market products of good quality rather than uncertified illegal products, and, at the same time, if illegal suppliers are targeted by repressive measures that drive them out of business. Raising the level of punishment and enforcing sanctions, not only against users of illegal drugs but more effectively against suppliers, enable authorities to implement higher legal prices for cannabis while undermining dealers.

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[40] See: Murphy, Kevin. 2019. "Cannabis Black Market Problem". *Forbes*. April 4. https://www.forbes.com/sites/kevinmurphy/2019/04/04/cannabis-black-market-problem/#76571956134f.

[41] Governor Cuomo signed legislation S.854-A/A.1248-A on 2021, March 31. See New York State Government, 2021. https://www.governor.ny.gov/news/governor-cuomo-signs-legislation-legalizing-adult-use-cannabis.

[42] Interestingly, this point of sale retail tax is coupled with a THC-potency-based tax on distributors, providing a comparative advantage to low-potency products resembling medical cannabis.

[43] The nation-wide legalization policy adopted in 2017 and 2018 took different forms across provinces. For instance in Alberta, home-cultivation is allowed (up to four plants) and online retail sales are managed by a government monopoly, while retail sales are left to private licensed stores. In Québec, one cannot home-grow cannabis and retail sales are organized by the government through the *Société Québécoise du Cannabis (SQDC)*.

[44] Liberal Party. 2015. "Real change: a new plan for a strong middle class". https://liberal.ca/wp-content/uploads/sites/292/2020/09/New-plan-for-a-strong-middle-class.pdf.

[45] In Québec, as of March 2019, SQDC stores only open from Wednesday to Sunday, "due to the current supply shortages (...) until product availability is more stable" (SQDC's website, www.sqdc.ca, March 19, 2019).

[46] See: Beaulieu, Marie-Cristina. 2020. "Cannabis Black Market". *Public Safety Canada*. June 15. https://www.publicsafety.gc.ca/cnt/trnsprnc/brfng-mtrls/prlmntry-bndrs/20200930/026/index-en.aspx. Updated February 8, 2021.

[47] Levinson-King, Robin. 2019. "Why Canada's cannabis bubble burst". *BBC News*. December 29. https://www.bbc.com/news/world-us-canada-50664578.

[48] See: Government of Canada, Health Infobase. 2022. "Cannabis use for non-medical purposes among Canadians (aged 16+)". December 16. https://health-infobase.canada.ca/cannabis/#a4.

[49] Since then, public authorities seem to have turned to investing in quality. See: Tomesco, Frédéric. 2022. "4 years after legalization, Quebec's cannabis stores want to smoke the black market". *The Montreal Gazette*. October 17. https://montrealgazette.com/business/local-business/4-years-after-legalization-quebecs-cannabis-stores-want-to-smoke-the-black-market.

Although our analysis focuses on how to achieve full legalization by eliminating the black market while containing consumption *post-legalization*, our general framework can be used to study a broader set of objectives. The optimal combinations of instruments depend on the policy objectives. These vary across settings and, in some cases, lead to the *status-quo* equilibrium where the market is regulated by dealers: prohibition is optimal when the government seeks to minimize the total consumption of cannabis. In other cases, coupling eviction pricing of legal cannabis with other policy instruments enables governments to reach desirable compounds of consumption and tax revenue targets. Extensions we discuss show how our policy mix can be fine-tuned to minimize the negative externalities entailed by cannabis use, to minimize the enforcement costs of policies, to maximize the consumer surplus or to maximize public resources raised through taxation of a legal sector. They highlight the (in)compatibility of some of these objectives, which is likely to give rise to unexpected or undesirable policy effects.

Finally, to shed more light on consumption behavior *post-legalization*, future research should account for the large heterogeneity of consumers, in particular regarding their risk aversion, intensive margin of consumption and liquidity constraints.

Declaration of competing interest

The authors declare that they have no relevant or material financial interests that relate to the research described in this paper.

Data availability

No data was used for the research described in the article.

Appendix A. Cannabis laws in the U.S.

As of February 2023, nineteen states and the District of Columbia have legalized the use of recreational cannabis. Cannabis possession remains a felony in other states such as Arizona, where sanctions and fines to enforce the law differ a lot. For example in Arizona, there is no guideline for punishment regarding small amounts of cannabis and possessing 2 pounds or less entails a risk of incarceration of up to 2 years and a fine of up to USD 150,000. In contrast, any amount on a first offense in Iowa is only a misdemeanor punishable by a maximum prison sentence of 6 months and a USD 1,000 fine.

The Table A.2 offers a synthetic overview of state cannabis laws across the United States. For each state, we reported the year during which cannabis was decriminalized in the second column. The third column records the year of the first ballot to legalize the use of medical cannabis, i.e. to instate a *Medical Marijuana Law* (MML), while the fourth column gives the year during which such a law was passed. The fifth column lists the year of the first ballot to legalize the recreational use of cannabis, and the sixth column the year of such a law being passed. The final column reports the year of the first legal retail sales of cannabis. Dashes represent the absence of the event described in the corresponding column.

Information on ballots was retrieved online from “Marijuana on the Ballot”, *Ballotpedia*, https://ballotpedia.org/Marijuana_on_the_ballot (last access: 11 September, 2023).

Table A.2
Cannabis regulation across the US.

State	Decrim.	1st MML ballot	MML	1st rec. ballot	Rec.	Retail
AL	-	-[a]	2021	-	-	-
AK	1975[b]	1998	1998	2000	2014	2016
AZ	-	1996	2010	2016	2020	2021
AR	-[c]	2012	2016	2022	-	-
CA	1975	1996	1996	1972	2016	2018
CO	1975	2000	2000	2012	2012	2014
CT	2011	-[a]	2012	-[d]	2021	2023
DE	2015	-[a]	2011	-	-	-
D.C.	2014	1998	2010	2014	2014	-[e]
FL	-[f]	2014	2016	-[g]	-	-
GA	-[f]	-	-[h]	-	-	-
HI	2020	- [a]	2000	-	-	-
ID	-	-	-	-	-	-
IL	2016	- [a]	2013	-[d]	2019	2020
IN	-[i]	-	-	-	-	-
IA	-	-	-	-	-	-
KS	-	-	-	-	-	-
KY	-[f]	-	-[j]	-	-	-
LA	2021	-[a]	2015[k]	-	-	-
ME	1975	1999	1999	2016	2016	2020
MD	2014	-[a]	2013	2022	2022	-[l]
MA	2008	2012	2012	2016	2016	2018
MI	2018	2008	2008	2018	2018	2019
MN	1976	-[a]	2014	-	-[m]	-
MS	1978	2020	2020	-	-	-
MO	2014	2018	2018	2022	2022	2023

(*continued on next page*)

Table A.2 (*continued.*)

State	Decrim.	1st MML ballot	MML	1st rec. ballot	Rec.	Retail
MT	-[f]	2004	2004	2020	2020	2022
NE	1979	-[n]	-	-	-	-
NV	2016	1998	1998	2006	2016	2017
NH	2017	-[a]	2013	-	-	-
NJ	-	-[a]	2010	2020	2020	2022
NM	2019	-[a]	2007	[d]	2021	2022
NY	1977	-[a]	2014	-[d]	2021	2022
NC	1977	-	-	-	-	-
ND	2019	2016	2016	2018	-	-
OH	1975	-[a]	2016	2015	-	-
OK	-	2018	2018	-[o]	-	-
OR	1973	1998	1998	2012	2014	2015
PA	-[f]	-[a]	2016	-	-	-
RI	2012	-[a]	2005	-[d]	2022	-
SC	-	-	-	-	-	-
SD	-	2006	2020	2020	-[p]	-
TN	-	-	-	-	-	-
TX	-[f]	-	-	-	-	-
UT	-	2018	2018	-	-	-
VT	2013	-[a]	2004	-[d]	2018	2020
VA	-	-	-	-[d]	2021	-[q]
WA	2012	1998	1998	2012	2012	2014
WV	-	-	2017[r]	-	-	-
WI	-[f]	-	-	-	-	-
WY	-	-	-	-	-	-

[a] *Medical Marijuana* was not on the ballot: instead, it was signed into law after legislative approval.
[b] Alaska issued a cannabis decriminalization bill on May 16, 1975, which is two weeks before the famous *Ravin* decision, protecting the possession of small amounts under constitutional privacy rights, was issued. Decriminalization of cannabis came into effect on June 5, 1975. The timeline of cannabis policy in Alaska then becomes fuzzy: further decriminalization was billed in 1982, then cannabis was recriminalized in 1990, decriminalized in 2003, then recriminalized in 2006; while the *Ravin* caselaw would still interact with the criminal state law (Brandeis, 2012). Legalization approved in 2014 ended this confusion.
[c] Although cannabis use remains a crime under state law, it is decriminalized locally.
[d] The recreational use of cannabis was not on the ballot: instead, it was signed into law after legislative approval.
[e] Implementation still pending.
[f] Although cannabis use remains a crime under state law, it is decriminalized locally.
[g] A cannabis legalization initiative was expected to be on the ballot in November 2022 and is now expected for November 2024.
[h] A bill was passed in 2015, legalizing the use of *light cannabis*, i.e. cannabis products featuring low THC potency (see Georgia General Assembly, https://www.legis.ga.gov/legislation/42674).
[i] Decriminalized in Marion County as of 2019 (see https://web.archive.org/web/20190930193952/https://www.wthr.com/article/marion-county-will-no-longer-prosecute-simple-marijuana-cases).
[j] A *Medical Marijuana* bill was presented to the House of Kentucky in January 2020. It is presently under evaluation by the Senate Judiciary Committee (Kentucky General Assembly, *House Bill 136*; retrieved online 3rd December 2020, url: https://apps.legislature.ky.gov/record/20rs/hb136.html).
[k] Although *Medical Marijuana* was signed into law in 2015, it was unlawful to inhale cannabis until 2019 (see https://www.mpp.org/states/louisiana/overview-of-louisianas-medical-cannabis-law/).
[l] Expected July 2023.
[m] In January 2023, the Minnesota House of Representatives introduced bill HF 100, which plans the legalization and regulation of adult-use cannabis (Minnesota House of Representatives, *HF 100*; retrieved online 8th February 2023, url:https://wdoc.house.leg.state.mn.us/leg/LS93/HF0100.0.pdf.
[n] A *Medical Marijuana* ballot is expected to be on the ballot in November 2024.
[o] A cannabis legalization ballot initiative was rejected March 2023.
[p] The recreational use of cannabis was legalized by the 2020 ballot. However, in 2021, the South Dakota Supreme Court ruled the amendment responsible for the legalization of recreational as unconstitutional.
[q] Expected in 2024.
[r] Although a bill regulating medical use of cannabis was signed in April 2017, Medical Marijuana Laws were not implemented in West Virginia before 2019.

Appendix B. Characterizing the marginal type of consumer θ^I, indifferent between no consumption and illegal consumption

An individual of type θ deciding between illegal consumption and no consumption considers the lottery $[-p-F, \theta v - p; q, 1-q]$. Not consuming entails a zero payoff. The utility associated with illegal consumption is given by: $w^+(1-q)u(\theta v - p) + w^-(q)u(-p-F)$, where u is a value function which is continuous, derivable and strictly increasing on $\mathbb{R}$, and such that $u(0) = 0$.

The consumption condition is written as: $w^+(1-q)u(\theta v - p) + w^-(q)u(-p-F) > 0$.

Let us define $V_I(\theta) = w^+(1-q)u(\theta v - p) + w^-(q)u(-p-F)$.

The marginal individual θ^I, indifferent between illegal consumption and no consumption, is characterized by:

$$V_I(\theta) = 0 \tag{B.1}$$

Since the value function u from not consuming is such that $u(0) = 0$, this condition is the same, whether θ^I is derived using expected utility theory or prospect theory. The only difference is that under expected utility theory, the weighting functions w^+ and w^- are equal to the identity. Since u is a function which is continuous, derivable, strictly increasing on $\mathbb{R}$, it admits a reciprocal function u^{-1} which is also strictly increasing and such that $u^{-1}(0) = 0$. Since $v > 0$, condition (B.1) is equivalent to:

$$\theta^I = \frac{u^{-1}\left(-\frac{w^-(q)}{w^+(1-q)}u(-p-F)\right) + p}{v} \tag{B.2}$$

We deduce that θ^I exists and is unique, with $\theta^I > \frac{p}{v}$ if $q > 0$ and $\theta^I = \frac{p}{v}$ if $q = 0$.

Expression (B.2) clearly shows that θ^I increases with q, p and F, since the value function u, its reciprocal and the weight functions are strictly increasing.

Finally, we focus on the absolute value of the price elasticity of demand, $\epsilon_{D,p}$, as defined in (4). After differentiating $\epsilon_{D,p}$ with respect to q, one can check that:

$$\frac{d\epsilon_{D^I,p}}{dq} = \frac{d\left\{\frac{g(\theta^I)}{1-G(\theta^I)}\right\}}{d\theta^I}\frac{d^2\theta^I}{dpdq}p + \frac{g(\theta^I)}{1-G(\theta^I)}\frac{d^2\theta^I}{dpdq}p. \tag{B.3}$$

As θ^I increases with p and q it follows that $\epsilon_{D^I,p}$ increases with $q \in [0,1]$ if the cross-derivative of θ^I with p and q is positive and if the distribution $G(\theta)$ satisfies the monotone hazard rate (MHR) property. We next check under what condition this cross derivative is positive.

Differentiating equation (B.1) yields: $\sum_{i\in\{p,q,\theta,F\}} \alpha_i \mathrm{d}i = 0$, with

$$\begin{cases} \alpha_\theta = vw^+(1-q)u'(\theta v - p) \\ \alpha_q = -w^{+\prime}(1-q)u(\theta v - p) + w^{-\prime}(q)u(-p-F) \\ \alpha_p = -w^+(1-q)u'(\theta v - p) - w^-(q)u'(-p-F) \\ \alpha_F = -w^-(q)u'(-p-F) \end{cases}$$

In particular, it yields $\frac{\mathrm{d}\theta^I}{\mathrm{d}p} = -\frac{\alpha_p}{\alpha_\theta}$. From this follows that

$$\frac{\mathrm{d}^2\theta^I}{\mathrm{d}p\mathrm{d}q} = \frac{\alpha_p\alpha_{\theta q} - \alpha_{pq}\alpha_\theta}{\alpha_\theta^2}$$

where

$$\begin{cases} \alpha_{pq} = \dfrac{\partial \alpha_p}{\partial q} = w^{+\prime}(1-q)u'(\theta v - p) - w^{-\prime}(q)u'(-p-F) \\ \alpha_{\theta q} = \dfrac{\partial \alpha_\theta}{\partial q} = -vw^{+\prime}(1-q)u'(\theta v - p) \end{cases}$$

Since the function u is increasing and the weight functions are positive and increasing, we show that $\alpha_p\alpha_{\theta q} - \alpha_{pq}\alpha_\theta > 0$ as follows:

$$\begin{aligned} & \left[w^-(q)w^{+\prime}(1-q) + w^{-\prime}(q)w^+(1-q)\right] vu'(\theta v - p)u'(-p-F) > 0 \\ \Rightarrow \quad & w^-(q)u'(-p-F)\,vw^{+\prime}(1-q)u'(\theta v - p) \\ & + w^{-\prime}(q)u'(-p-F)\,vw^+(1-q)u'(\theta v - p) > 0 \\ \Rightarrow \quad & \alpha_p\alpha_{\theta q} - \alpha_{pq}\alpha_\theta > 0 \end{aligned}$$

We conclude that $\frac{\mathrm{d}^2\theta^I}{\mathrm{d}p\mathrm{d}q} > 0$ and that $\epsilon_{D^I,p}$ increases with $q \in [0,1]$ if the distribution $G(\theta)$ satisfies the monotone hazard rate (MHR) property.

Appendix C. Characterizing the marginal consumer $\theta^L(p, p^L)$, indifferent between legal and illegal consumption

A consumer of type θ deciding between legal and illegal consumption faces a choice between a certain payoff of $\theta bv - p^L$ and the lottery $[-p-F, \theta v - p; q, 1-q]$. Note first that individuals with $\theta \le 0$ will never purchase cannabis, whether it is legal or not. Second if $\theta v - p \le \theta bv - p^L$ the only possibility is that individuals buy either the legal product or nothing. Symmetrically if $\theta v - p > 0 > \theta bv - p^L$ the only possibility is that they either purchase on the black market or not at all. It implies that a necessary condition for some consumers being willing to purchase cannabis illegally, while others prefer to purchase it legally, is that there exists some $\theta > 0$ such that $\theta v - p > \theta bv - p^L > 0$, or equivalently $\frac{p^L - p}{(b-1)v} > \theta > \frac{p^L}{bv}$. This requires that $\frac{p^L - p}{(b-1)v} > \frac{p^L}{bv}$ or equivalently $p^L > bp$.

C.1. Under expected utility theory

If individuals are expected utility maximizers the marginal consumer, indifferent between legal and illegal consumption, solves the following equation: $(1-q)u(\theta v - p) + qu(-p-F) = u\left(\theta bv - p^L\right)$. Let

$$V_1(\theta) \equiv (1-q)u(\theta v - p) + qu(-p-F) - u\left(\theta bv - p^L\right) \tag{C.1}$$

If $\theta^L > 0$ exists, it is such that $V_1(\theta) = 0$.

We deduce that for $\frac{p^L-p}{(b-1)v} > \theta > \frac{p^L}{bv}$, $V_1'(\theta) = (1-q)vu'(\theta v - p) - bvu'\left(\theta bv - p^L\right) < 0$ since u' is decreasing (i.e., u is concave) and $1-q \le 1$, $\theta v - p > \theta bv - p^L$, $b > 1$. Hence, if $\theta^L > 0$ exists, it is unique. We have that: $V_1\left(\frac{p^L-p}{(b-1)v}\right) = -q\left[u\left(\frac{p^L-bp}{b-1}\right) - u(-p-F)\right] < 0$. Since $V_1(\theta)$ is decreasing for $\theta \in [\frac{p^L}{bv}, \frac{p^L-p}{(b-1)v}]$, to finish the proof we need to find the condition under which $V_1\left(\frac{p^L}{bv}\right) > 0$. Therefore, whenever

$$(1-q)u\left(p^L - \frac{bp}{b}\right) > -qu(-p-F) \tag{C.2}$$

the equation $V_1(\theta) = 0$ admits a unique solution.

Differentiating equation (C.1) yields $\alpha_q \mathrm{d}q + \alpha_{p^L}\mathrm{d}p^L + \alpha_p \mathrm{d}p + \alpha_F \mathrm{d}F + \alpha_{\theta^L}\mathrm{d}\theta^L + \alpha_b \mathrm{d}d = 0$ with

$$\begin{cases} \alpha_q = u(-p-F) - u\left(\theta^L v - p\right) & < 0 \\ \alpha_{p^L} = u'\left(\theta^L v - p^L\right) & > 0 \\ \alpha_p = -qu'(-p-F) - (1-q)u'\left(\theta^L v - p\right) & < 0 \\ \alpha_F = -qu'(-p-F) & < 0 \\ \alpha_{\theta^L} = v(1-q)u'\left(\theta^L v - p\right) - bvu'\left(\theta^L bv - p^L\right) & < 0 \\ \alpha_b = -\theta^L vu'\left(\theta^L bv - p^L\right) & < 0 \end{cases}$$

It is straightforward to show that θ^L decreases with q, p, F and b, while it increases with p^L.

C.2. Under prospect theory

Under CPT the consumer's reference level of wealth is provided by the risk free option, $\theta bv - p^L$. A potential cannabis consumer deciding between buying from the black market or from the legal sector considers the lottery $[p^L - p - F - \theta bv, p^L - p + \theta(1-b)v; q, 1-q]$. Let

$$V_2(\theta) = w^+(1-q)u\left(p^L - p - (b-1)v\theta\right) + w^-(q)u\left(-p - F - \theta bv + p^L\right) \tag{C.3}$$

The marginal consumer, $\theta^L(p, p^L)$, indifferent between legal and illegal consumption solves $V_2(\theta) = 0$. Since $b \ge 1$ and u is strictly increasing, we have

$$\begin{aligned} V_2'(\theta) = &-(b-1)vw^+(1-q)u'\left(\theta(1-b)v - p + p^L\right) \\ &- bvw^-(q)u'\left(-p - F - \theta bv + p^L\right) \\ < &\ 0 \end{aligned}$$

We have: $V_2\left(\frac{p^L-p}{(b-1)v}\right) = w^-(q)u\left(p - p^L - (b-1)F\right) < 0$ since $p^L > bp \ge p$. The strict monotonicity of $V_2(\theta)$ implies that θ^L exists and is unique whenever $V_2\left(\frac{p^L}{bv}\right) > 0$. This is equivalent to:

$$w^+(1-q)u\left(p^L - \frac{bp}{b}\right) > -w^-(q)u(-p-F) \tag{C.4}$$

Condition (C.4) under CPT is equivalent to (C.2) under EUT, where the probability weighting function is the identity. In both cases these conditions imply that $\theta^L > 0$ exists and is unique.

Differentiating equation (C.3) yields: $\alpha_{\theta^L}\mathrm{d}\theta^L + \alpha_q \mathrm{d}q + \alpha_{p^L}\mathrm{d}p^L + \alpha_p \mathrm{d}p + \alpha_F \mathrm{d}F + \alpha_d \mathrm{d}d = 0$ with

$$\begin{cases} \alpha_{\theta^L} = -w^-(q)vu'\left(p^L - p - F - \theta^L bv\right) - w^+(1-q)(d-1)vu'\left(p^L - p + \theta^L(1-b)v\right) & < 0 \\ \alpha_q = w^{-\prime}(q)u\left(p^L - p - F - \theta^L bv\right) - w^{+\prime}(1-q)u\left(p^L - p + \theta^L(1-b)v\right) & < 0 \\ \alpha_{p^L} = w^-(q)u'\left(p^L - p - F - \theta^L bv\right) + w^+(1-q)u'\left(p^L - p + \theta^L(1-b)v\right) & > 0 \\ \alpha_p = -w^-(q)u'\left(p^L - p - F - \theta^L bv\right) - w^+(1-q)u'\left(p^L - p + \theta^L(1-b)v\right) & < 0 \\ \alpha_F = -w^-(q)u'\left(p^L - p - F - \theta^L bv\right) & < 0 \\ \alpha_b = -\theta^L vw^+(1-q)u'\left(p^L - p + \theta^L(1-b)v\right) - \theta vqu'\left(-p - F - \theta bv + p^L\right) & < 0 \end{cases}$$

It is straightforward to show that θ^L decreases with q, p, F and b, while it increases with p^L.

C.3. On the sensitivity of the price elasticity on the illegal market to the legal price

Finally, let us focus on the absolute value of the price elasticity of demand on the illegal market, $\epsilon_{D,p}$, when both the illegal and the legal markets are active and its sensitivity to the legal price p^L. To this purpose, we differentiate $\varepsilon_{D^I,p}$ with respect to p^L.

$$\begin{aligned}\frac{d\varepsilon_{D^I,p}}{dp^L} =& \frac{d\frac{g(\theta^I)}{G(\theta^L)-G(\theta^I)}}{d\theta^L}\frac{d\theta^L}{dp^L}\frac{d\theta^I}{dp}p \\ &-\frac{d\frac{g(\theta^L)}{G(\theta^L)-G(\theta^I)}}{d\theta^L}\frac{d^2\theta^L}{dpdp^L}p \\ &-\frac{g(\theta^L)}{G(\theta^L)-G(\theta^I)}\frac{d^2\theta^L}{dpdp^L}p\end{aligned} \tag{C.5}$$

Since, $\frac{d\frac{g(\theta^I)}{G(\theta^L)-G(\theta^I)}}{d\theta^L}<0$, $\frac{d\theta^L}{dp^L}>0$ and $\frac{d\theta^I}{dp}>0$, the first term of (C.5) is negative.

When both the legal and the illegal sectors are active, $\theta^I<\theta^L$ and hence $G(\theta^I)<G(\theta^L)<1$. It follows that $\frac{g(\theta^L)}{G(\theta^I)-G(\theta^L)}<0$. Assuming the distribution $G(\theta)$ satisfies the monotone hazard rate (MHR) property as verified by a large class of distributions, $\frac{g(\theta^L)}{1-G(\theta^L)}>0$ increases with θ^L. Therefore, $\frac{g(\theta^L)}{G(\theta^I)-G(\theta^L)}$ decreases with θ^L: $\frac{d\frac{g(\theta^L)}{G(\theta^I)-G(\theta^L)}}{d\theta^L}<0$.

Further, $\frac{d^2\theta^L}{dpdp^L}>0$. Indeed, the differentiation of equations (C.1) or alternatively (C.3) yields $\frac{\mathrm{d}\theta^L}{\mathrm{d}p}=-\frac{\alpha_p}{\alpha_\theta^L}$, where the quantities α_p and α_θ^L are defined in sections Appendix C.1 and Appendix C.2 respectively. From this follows that

$$\frac{\mathrm{d}^2\theta^L}{\mathrm{d}p\mathrm{d}p^L}=\frac{\alpha_p\alpha_{\theta^Lp^L}-\alpha_{pp^L}\alpha_{\theta^L}}{\alpha^2_{\theta^L}}$$

We show below that $\alpha_p\alpha_{\theta^Lp^L}-\alpha_{pp^L}\alpha_{\theta^L}>0$ and $\frac{\mathrm{d}^2\theta^L}{\mathrm{d}p\mathrm{d}p^L}>0$. We conclude that $\frac{d\varepsilon_{D^I,p}}{dp^L}<0$: as the price on the legal market p^L increases, consumers become less elastic to the black-market price p.

Under EUT

$$\begin{cases}\alpha_{pp^L}=0\\ \alpha_{\theta^Lp^L}=bvu''\left(\theta^Lbv-p^L\right)\quad<0\end{cases}$$

Since $\alpha_p<0$, it is straightforward that $\frac{\mathrm{d}^2\theta^L}{\mathrm{d}p\mathrm{d}p^L}>0$.

Under CPT

$$\begin{cases}\alpha_{pp^L}=\frac{\partial\alpha_p}{\partial p^L}\\ \qquad=-w^-(q)u''\left(p^L-p-F-\theta^Lbv\right)-w^+(1-q)u''\left(p^L-p+\theta^L(1-b)v\right)\\ \alpha_{\theta^Lp^L}=\frac{\partial\alpha_\theta^L}{\partial p^L}\\ \qquad=v\alpha_{pp^L}-w^+(1-q)(d-2)vu''\left(p^L-p+\theta^L(1-b)v\right)\end{cases}$$

Since $\alpha_{\theta^L}=v\alpha_p-w^+(1-q)(d-2)vu'\left(p^L-p+\theta^L(1-b)v\right)$, we can rewrite

$$\begin{aligned}&\alpha_p\alpha_{\theta^Lp^L}-\alpha_{pp^L}\alpha_{\theta^L}\\ =&\,\alpha_p\left(v\alpha_{pp^L}-w^+(1-q)(d-2)vu''\left(p^L-p+\theta^L(1-b)v\right)\right)\\ &-\alpha_{pp^L}\left(v\alpha_p-w^+(1-q)(d-2)vu'\left(p^L-p+\theta^L(1-b)v\right)\right)\\ =&-\alpha_pw^+(1-q)(d-2)vu''\left(p^L-p+\theta^L(1-b)v\right)\\ &+\alpha_{pp^L}w^+(1-q)(d-2)vu'\left(p^L-p+\theta^L(1-b)v\right)\end{aligned}$$

Besides,

$$\begin{aligned}&-\alpha_pu''\left(p^L-p+\theta^L(1-b)v\right)+\alpha_{pp^L}u'\left(p^L-p+\theta^L(1-b)v\right)\\ =&w^-(q)u'\left(p^L-p-F-\theta^Lbv\right)u''\left(p^L-p+\theta^L(1-b)v\right)\end{aligned}$$

$$
\begin{aligned}
&+ w^{+}(1-q)u'\left(p^L - p + \theta^L(1-b)v\right)u''\left(p^L - p + \theta^L(1-b)v\right)\\
&- w^{-}(q)u''\left(p^L - p - F - \theta^L bv\right)u'\left(p^L - p + \theta^L(1-b)v\right)\\
&- w^{+}(1-q)u''\left(p^L - p + \theta^L(1-b)v\right)u'\left(p^L - p + \theta^L(1-b)v\right)\\
=&w^{-}(q)u'\left(p^L - p - F - \theta^L bv\right)u''\left(p^L - p + \theta^L(1-b)v\right)\\
&- w^{-}(q)u''\left(p^L - p - F - \theta^L bv\right)u'\left(p^L - p + \theta^L(1-b)v\right)\\
&< 0
\end{aligned}
$$

Hence, $\alpha_p \alpha_{\theta^L p^L} - \alpha_{pp^L}\alpha_{\theta^L} > 0$ and $\frac{\mathrm{d}^2\theta^L}{\mathrm{d}p\mathrm{d}p^L} > 0$.

Appendix D. Consumers facing legalization

D.1. Consumer choices

Reminder Appendix B shows that consumer θ^I, indifferent between illegal consumption and no consumption in the prohibition environment is defined as the implicit solution of equation (2), i.e. $V_I(\theta) = w^+(1-q)u(\theta v - p) + w^-(q)u(-p-F) = 0$, where the weighting functions are the identity function under EUT. Any type higher than θ^I consumes cannabis under prohibition.

Appendix C shows that consumer θ^L, indifferent between legal and illegal consumption, solves under

- EUT:

$$V_1(\theta) = (1-q)u(\theta v - p) + qu(-p-F) - u\left(\theta bv - p^L\right) = 0$$

- CPT:

$$
\begin{aligned}
V_2(\theta) =&w^+(1-q)u\left(p^L - p - \theta(b-1)v\right)\\
&+ w^-(q)u\left(-p - F - \theta bv + p^L\right) = 0
\end{aligned}
$$

Any type higher than θ^L prefers to purchase cannabis legally than illegally.

This appendix shows that $\tilde{p}^L(p) = \theta^I bv$, with θ^I solution of (2), is the threshold price of legal cannabis under which the dealers exit the market if they sell their product at price p.

To push dealers out of the market when they sell illegal products at price p, θ^L must be pushed under θ^I. The maximum price of legal cannabis such that dealers are pushed out of business at price p is the solution of $w^+(1-q)u\left(p^L - p - \theta(b-1)v\right) + w^-(q)u\left(-p - F - \theta bv + p^L\right) = 0$, for θ^I, solution of (2).

Replacing $p^L = \theta^I bv$ in the equation above, we can write $w^+(1-q)u\left(p^L - p - \theta(b-1)v\right) + w^-(q)u\left(-p - F - \theta bv + p^L\right) = w^+(1-q)u(\theta^I v - p) + w^-(q)u(-p-F)$, which is equal to 0 since θ^I, is solution of (2).

This demonstrates that $\tilde{p}^L(p) = \theta^I bv$, with θ^I solution of (2), is this threshold price.

We next compare θ^0, θ^L and θ^I depending on whether the legal price, p^L, is higher than $\tilde{p}^L(p)$ or not.

Under legalization, the consumer θ^0, indifferent between legal consumption and no consumption, is characterized by $u\left(\theta^0 bv - p^L\right) = 0$. Any consumer with type higher than $\theta^0 = \frac{p^L}{bv}$ prefers to purchase cannabis legally than not consume cannabis.

Two cases may follow the implementation of a legal market.

Condition $p^L \le \tilde{p}^L(p)$ holds We can write, for $i = 1, 2$, $V_i(\theta^0) = w^+(1-q)u(\frac{p^L}{b} - p) + w^-(q)u(-p-F)$, with the weighting functions being the identity function under EUT.

By definition of θ^L and θ^I, $V_i(\theta^L) = 0$ and $V_I(\theta^I) = 0$. If $p^L \le \theta^I bv$ then $\frac{p^L}{b} \le \theta^I v$. Since the function $u(.)$ is strictly increasing, $\frac{p^L}{b} \le \theta^I v$, implies that: $V_i(\theta^0) = w^+(1-q)u\left(\frac{p^L}{b} - p\right) + w^-(q)u(-p-F) \le V_I(\theta^I) = 0$. Since the function $V_i(\theta)$ is strictly decreasing in θ, $V_i(\theta^L) = 0$ and $V_i(\theta^0) \le 0$ imply $\theta^L \le \theta^0$.

Finally, since $V_I(\theta)$ is strictly increasing in θ, $\theta^0 \le \theta^I \Leftrightarrow V_I(\theta^0) = w^+(1-q)u\left(\frac{p^L}{b} - p\right) + w^-(q)u(-p-F) \le V_I(\theta^I)$. Since $V_I(\theta^I) = 0$ and $V_I(\theta^0) \le 0$, we deduce that $\theta^0 \le \theta^I$.

We have demonstrated in this condition that $\theta^L \le \theta^0 \le \theta^I$: the legalization has the effect of drying up the illegal market.

Condition $p^L > \tilde{p}^L(p)$ holds The reasoning is similar to the previous case but the inequalities are inverted.

The condition $p^L > \theta^I bv$, leads to $V_i(\theta^0) > V_i(\theta^L) = 0$ such that $\theta^0 < \theta^L$.

Similarly, since $V_I(\theta)$ is strictly increasing in θ, $V_I(\theta^0) = w^+(1-q)u\left(p^L - \frac{bp}{b}\right) + w^-(q)u(-p-F) > 0$ and $V_I(\theta^I) = 0$ imply that $\theta^I < \theta^0$. We have demonstrated in this condition that $\theta^I < \theta^0 < \theta^L$: the illegal market survives.

D.2. Proof of Proposition 1 (the demand)

The black market responds strategically to the legal market by lowering its price to $p^N(p^L)$, the solution of (6) computed with $\varepsilon_{D^I,p} = -\frac{\partial D^I(p,p^L)}{\partial p}\frac{p}{D^I(p,p^L)}$, the direct price elasticity of the demand $D^I(p,p^L)$ defined in (9)), which depends on p^L. The price reaction function of the black-market sellers solves the following equation:

$$p(p^L) = \begin{cases} p^N(p^L) & \text{if } c \le p^N(p^L) < \frac{p^L}{b} \\ \varnothing & \text{otherwise} \end{cases} \tag{D.1}$$

Since θ is distributed on $\mathbb{R}$, as long as $p^L < \infty$, there is a positive demand for legal cannabis $(1 - G(\theta^L(p,p^L)) > 0)$.

If $p^L > \tilde{p}^L(p)$ $(\theta^I < \theta^0 < \theta^L)$ and other policy parameters (c, b, q, F) are held constant, the demand for the black-market product decreases following legalization and the absolute value of the price elasticity of the black-market demand increases. Therefore, for any finite legal retail price p^L, the black-market price p decreases after legalization. This implies that the demand for cannabis increases (θ^I decreases).

If $p^L \le \tilde{p}^L(p)$ $(\theta^L \le \theta^0 \le \theta^I)$, it is obvious that the overall demand for legal cannabis increases following legalization. We deduce that legalization always increases the overall demand for cannabis, when the operation costs of illegal providers, the quality differential and the repression of demand on the black market are held constant.

Appendix E. Pricing out the dealers

E.1. Proof of Proposition 2 (characterization of the eviction price)

Under prospect theory the threshold price, denoted $\underline{p}^L$, below which the criminals exit the market is such that $\theta^L(c,\underline{p}^L) = \theta^I(c)$, where $\theta^I(c)$ and $\theta^L\left(c,\underline{p}^L\right)$ are defined in equations (2) and (7) with $p = c$. Therefore, $\theta^I(c)$ (or equivalently $\theta^L\left(c,\underline{p}^L\right)$) is determined by the following system of equations:

$$\begin{cases} w^+(1-q)u(\theta v - c) + w^-(q)u(-c-F) = 0 \\ w^+(1-q)u\left(\theta v - \theta b v + \underline{p}^L - c\right) + w^-(q)u\left(-\theta b v + \underline{p}^L - c - F\right) = 0 \end{cases}$$

Under expected utility theory, the same reasoning yields the following system of equations

$$\begin{cases} (1-q)u(\theta v - c) + qu(-c-F) = 0 \\ (1-q)u(\theta v - c) + qu(-c-F) = u\left(\theta b v - p^L\right) \end{cases}$$

In both cases, this yields $\underline{p}^L = dv\theta^I(c)$.

The legal demand is at the same level as if illegal suppliers were pricing at marginal cost:

$$D^L(\underline{p}^L) = \int_{\theta^L(\underline{p}^L,c)}^{+\infty} g(\theta)d\theta = 1 - G\left(\theta^L(\underline{p}^L,c)\right) = 1 - G(\theta^I(c)) = D^I(c). \tag{E.1}$$

E.2. Proof of the corollary to Proposition 2

The price $\underline{p}^L = bv\theta^I(c)$ being linear in the quality differential b and the parameters θ^I and v being positive, it is straightforward that $\underline{p}^L$ increases with b. Regarding the other parameters, comparative statics are derived in Appendix B with $p = c$.

Appendix F. Enlarging the set of objectives

F.1. Proof of Proposition 3 (cost effectiveness under a demand target)

Consider the case of a government interested in eradicating the illegal market while containing the (legal) use of cannabis to a level $D^L(\underline{p}^L) = \bar{D}$. Such a government then applies the eviction price $\underline{p}^L$ defined in Proposition 2 and such that $D^L(\underline{p}^L) \le \bar{D}$.

In this case, the optimal combination of policy instruments, minimizing the net enforcement cost $C(e,b,\tau) = E(\delta,q)$, is solution of the following program:

$$\begin{aligned} &\min_{\delta,q} E(\delta,q) \\ &\text{s.t. } D^L(\underline{p}^L) \le \bar{D} \text{ with } \underline{p}^L = bv\theta^I((1+\delta)c^L) \end{aligned} \tag{F.1}$$

The Lagrangian of this optimization problem is

$$\mathcal{L} = E(\delta,q) + \lambda\left[\bar{D} - D^L(\underline{p}^L)\right]$$

The Lagrangian derivatives with respect of δ and q are given as follows

$$\frac{\partial E(\delta,q)}{\partial \delta} - \lambda \frac{\partial D^L(\underline{p}^L)}{\partial \delta} = 0$$
$$\frac{\partial E(\delta,q)}{\partial q} - \lambda \frac{\partial D^L(\underline{p}^L)}{\partial q} = 0$$

Focusing on interior solutions, these yield $\frac{\frac{\partial D^L(\underline{p}^L)}{\partial q}}{\frac{\partial D^L(\underline{p}^L)}{\partial \delta}} = \frac{\frac{\partial E(\delta,q)}{\partial q}}{\frac{\partial E(\delta,q)}{\partial \delta}}$, i.e. the optimality condition (12) and, at the optimum, the demand constraint $D^L(\underline{p}^L) = \bar{D}$ is binding.

F.2. Maximizing tax revenue

Proof of Proposition 5

In this section we aim to derive the optimal tax rate when the government seeks to maximize tax revenue. It solves: $\max_\tau \tau c^L D^L\left(p,(1+\tau)c^L|b\right)$. The first order condition of this optimization program is:

$$c^L D^L\left(p,(1+\tau)c^L|b\right) + \tau c^L \frac{\partial D^L}{\partial \tau} = 0$$

which is equivalent to:

$$D^L\left(p,(1+\tau)c^L|b\right) + \tau \frac{\partial D^L}{\partial \tau} = 0$$

If $p^L > \tilde{p}^L$, $D^L\left(p,(1+\tau)c^L|b\right) = 1 - G\left(\theta^0\right)$, with $\theta^0 = \frac{p^L}{bv}$ (cf. Section 4.2).

$$\begin{aligned}
& D^L\left(p,(1+\tau)c^L|b\right) + \tau \frac{\partial D^L}{\partial \tau} = 0 \\
\Leftrightarrow & 1 - G\left(\frac{p^L}{bv}\right) + \tau \frac{\partial\left\{1 - G\left(\frac{p^L}{bv}\right)\right\}}{\partial \tau} = 0 \\
\Leftrightarrow & 1 - G\left(\frac{p^L}{bv}\right) = \tau \frac{\partial\left\{G\left(\frac{p^L}{bv}\right)\right\}}{\partial \tau} \\
\Leftrightarrow & 1 - G\left(\frac{p^L}{bv}\right) = \tau \frac{\partial\left\{G\left(\frac{(1+\tau)c^L}{bv}\right)\right\}}{\partial \tau} \\
\Leftrightarrow & 1 - G\left(\frac{p^L}{bv}\right) = \tau \frac{c^L}{bv} g\left(\frac{(1+\tau)c^L}{bv}\right) \\
\Leftrightarrow & 1 - G\left(\theta^0\right) = \tau c^L \underbrace{\frac{1}{bv}}_{=\frac{\partial \theta^0}{\partial p^L}} g\left(\theta^0\right)
\end{aligned}$$

Otherwise, $D^L\left(p,(1+\tau)c^L|b\right) = 1 - G\left(\theta^L\right)$ and

$$\begin{aligned}
& D^L\left(p,(1+\tau)c^L|b\right) + \tau \frac{\partial D^L}{\partial \tau} = 0 \\
\Leftrightarrow & 1 - G\left(\theta^L\right) + \tau \frac{\partial\left\{1 - G(\theta^L)\right\}}{\partial \tau} = 0 \\
\Leftrightarrow & 1 - G\left(\theta^L\right) = \tau \frac{\partial\left\{G(\theta^L)\right\}}{\partial \tau} \\
\Leftrightarrow & 1 - G\left(\theta^L\right) = \tau \frac{\partial \theta^L}{\partial \tau} g(\theta^L) \\
\Leftrightarrow & 1 - G\left(\theta^L\right) = \tau \frac{\partial \theta^L}{\partial p^L} \frac{\partial p^L}{\partial \tau} g(\theta^L) \\
\Leftrightarrow & 1 - G\left(\theta^L\right) = \tau \frac{\partial \theta^L}{\partial p^L} c^L g(\theta^L)
\end{aligned}$$

This yields equation (15).

Maximizing tax revenue when θ follows an exponential distribution

Let us assume that on the positive real line, θ follows an exponential distribution $G(\theta) \equiv 1 - e^{-\eta\theta}$, with $0 < \eta < 1$, equation (15) becomes

$$1 = \eta c^L \tau \frac{\partial \theta^l}{\partial p^L}. \tag{F.2}$$

If the black market has been initially shut down, then (F.2) yields $\tau_0^{\alpha_T} = \frac{bv}{\eta c^L}$. If the black market is not shut down, with risk-neutral consumers we have $\theta^L = \frac{p^L - p - qF}{(b+q-1)v}$, so that (F.2) yields: $\tau^{\alpha_T} = \frac{b+q-1}{\eta c^L} v \geq 0$. This is the optimal solution if the demand for cannabis is strictly positive for this level of taxes which requires that $\theta^L(\tau^{\alpha_T}) = \frac{(1+\tau^{\alpha_T})c^L - p - qF}{(b+q-1)v} > 0$. This is equivalent to $\eta < \frac{v(b+q-1)}{qF+p-c^L} \leq \frac{v(b+q-1)}{qF+\delta c^L} = \eta^{\alpha_T}$. We deduce that the unconstrained solution (i.e., in the absence of competition by the black market) leads to a larger excise tax than the constrained solution: $\tau_0^{\alpha_T} \geq \tau^{\alpha_T}$,[50] which is intuitive.

When the government does not have to deal with competition it can impose higher taxes, as the consumers are captive. In both cases, the tax rate increases with vb, the quality of the legal product, and decreases with c^L, the marginal cost of production of legal cannabis, and with η, the distribution of consumers' type parameter. Indeed, a higher η implies that the distribution of taste is skewed towards the low values of θ: few people are willing to pay a high price for cannabis, which implies that the tax rate should be relatively low.

Next, we check under which conditions the optimal tax level τ^{α_T} is such that the final price $p^L(\tau^{\alpha_T}) = (1+\tau^{\alpha_T})c^L$ is lower than the eviction price $\underline{p}^L = bv\theta^I((1+\delta)c^L) = b\frac{(1+\delta)c^L + qF}{1-q}$. Let $\eta^{evic} = \frac{(1-q)(b+q-1)v}{b(\delta c^L + qF) + (b+q-1)c^L} > 0$. It is easy to check that if $\eta \geq \eta^{evic}$, then $p^L(\tau^{\alpha_T}) \leq \underline{p}^L$. Under our assumptions, $0 < \eta^{evic} < \eta^{\alpha_T}$. Only when $\eta^{evic} \leq \eta < \eta^{\alpha_T}$ is it possible to maximize tax revenues while simultaneously eradicating the black market through an eviction price.

Based on the number of users of cannabis worldwide, it is unrealistic to assume that the distribution of tastes for cannabis in the general population is skewed towards the low values of θ (i.e., it is unrealistic to consider large values for η). Yet, if $\eta < \eta^{evic} < \eta^{\alpha_T}$, then the price that maximizes tax revenue is higher than the eviction price. In other words, when there is a large demand for cannabis, maximizing tax revenue implies setting the price of the legal products relatively high, such that the black market can survive by selling illegal cannabis at a discount.

Taxation and survival of the black market

After the government chooses the price of the legal cannabis, $p^L = (1+\tau)c^L$, the repression (i.e. the probability of arrest q, the fine F and the increase in marginal cost to produce illegally $\delta \geq 0$), as well as the quality differential between legal and illegal products, $b \geq 1$, the consumers decide whether to consume or not, and on which market. From here, two cases may occur.

1. Taxes are set low enough such that, given the level of repression on both the demand and supply sides and the quality differential, the black market does not survive. In this case τ satisfies $1+\tau \leq bv\frac{\theta^I((1+\delta)c^L)}{c^L}$ where $\theta^I\left((1+\delta)c^L\right)$ is defined in (2). Let $\theta^0 = \frac{(1+\tau)c^L}{vb}$ be the agent indifferent between consuming legal cannabis at price $p^L = (1+\tau)c^L$ and not consuming. The demand for (legal) cannabis is given by: $D^L\left((1+\tau)c^L\right) = 1 - G\left(\frac{(1+\tau)c^L}{vb}\right)$.
2. If the government sets taxes too high, i.e. such that

$$(1+\tau)c^L > bv\theta^I\left((1+\delta)c^L\right),$$

then the demand is split between the legal and illegal markets, as follows:

$$D^L\left(p,(1+\tau)c^L|b\right) = 1 - G\left(\theta^L\left(p,(1+\tau)c^L|b\right)\right)$$
$$D^I\left(p,(1+\tau)c^L|b\right) = G\left(\theta^L\left(p,(1+\tau)c^L|b\right)\right) - G\left(\theta^I(p)\right)$$

where $\theta^I(p)$ is defined in (2) and $\theta^L\left(p,(1+\tau)c^L|b\right)$ in (7).
Illegal providers set the black-market price p as defined in (6). The price reaction function of the illegal sector is analogous to the best response described in (10) with $p^L = (1+\tau)c^L$.

Appendix G. Application to Tversky and Kahneman (1992)

Tversky and Kahneman (1992) introduces a model featuring loss aversion, diminishing sensitivity for gains and losses and diminishing sensitivity regarding probabilities. Agents' appreciation for gains and losses is represented by a value function $u(x)$, which is S-shaped and has an inflection point in zero. This describes individuals being empirically risk-averse for gains and risk-seeking for losses; called by Kahneman and Tversky (1979) the *reflection effect*.

More specifically, the authors calibrate the following functional form for the value function:

$$u(x) = \begin{cases} x^\alpha \text{ , if } x > 0 \\ -\lambda(-x)^\beta \text{ , if } x \leq 0 \end{cases} \tag{G.1}$$

[50] They are equal only when $q = 1$.

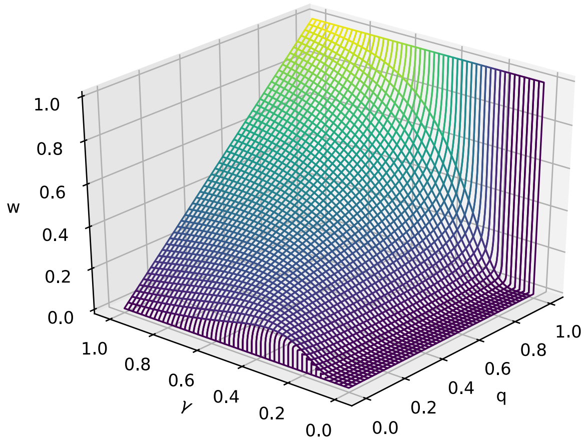

Fig. G.5. Probability weighting functions for $\gamma \in (0, 1]$.

where $\alpha, \beta \in (0, 1)$ capture the degree of risk preference of individuals who are risk-averse for gains and risk-seeking for losses. $\lambda \geq 1$ is the *coefficient of loss aversion*, which reflects that the decrease in utility from a loss is greater than the increase in utility from a gain of the same amount. In line with Tversky and Kahneman (1992) estimates, we assume $\alpha = \beta$.

The weighting functions w^+, for gains, w^-, for losses are concave near 0 and convex near 1 to capture diminishing sensitivity for probabilities. Tversky and Kahneman (1992) specify the weighting functions as follows:

$$w^x(q) = \frac{q^{\gamma^x}}{\left(q^{\gamma^x} + (1-q)^{\gamma^x}\right)^{\frac{1}{\gamma^x}}} \qquad \text{with } x = +, -.$$

The form of such weighting functions is represented in Fig. G.5. For $\gamma = 1$, $w^x : q \mapsto \frac{q^\gamma}{(q^\gamma + (1-q)^\gamma)^{\frac{1}{\gamma}}}$ is the identity. The closer γ is to 0, the more distorted the probability weights are. When $\gamma \to 0$, the function w^x has an L-shape.

In line with Tversky and Kahneman (1992), we assume that $\gamma^+ < \gamma^-$.

Eviction price under Tversky and Kahneman (1992)

Substituting in equation (B.2) the value function u specified in (G.1), the type θ^I indifferent between consuming illegally and not consuming is given by:

$$\theta^I = \frac{1}{v}\left[\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} (F + p) + p\right] \tag{G.2}$$

This implies that:

$$\frac{\partial \theta^I}{\partial p} = \frac{1}{v}\left[\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} + 1\right] > 0$$

Let us note $\omega(q) \equiv \frac{w^-(q)}{w^+(1-q)}$, which is strictly increasing since w^x is increasing for $x = +, -$. It yields:

$$\frac{\partial \theta^I}{\partial q} = \frac{\lambda^{\frac{1}{\alpha}} (F + p)}{\alpha v} \omega'(q) \left[\omega(q)\right]^{\frac{1-\alpha}{\alpha}} > 0.$$

We deduce that the eviction price $\underline{p}^L = bv\theta^I(c)$ under Tversky and Kahneman (1992)'s specification is:

$$\underline{p}^L = b\left[\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} (F + c) + c\right]. \tag{18}$$

Comparative statics of the eviction price

We can check straightforwardly how the eviction price varies when the policy parameters change (see corollary to Proposition 2 already demonstrated in the general case).

- $$\frac{\partial \underline{p}^L}{\partial F} = b\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} > 0$$
- $$\frac{\partial \underline{p}^L}{\partial c} = b\left[\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} + 1\right] > 0$$
- $$\frac{\partial \underline{p}^L}{\partial b} = \left[\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} (F+c) + c\right] > 0$$
- $$\frac{\partial \underline{p}^L}{\partial q} = -b\frac{(F+c)\lambda^{\frac{1}{\alpha}}}{\alpha}\frac{\omega'(q)}{\omega^2(q)} > 0$$

Marginal consumer indifferent between legal and illegal consumption

Under the Tversky and Kahneman (1992) specification, one can solve for the type θ^L indifferent between consuming legal and black-market cannabis, substituting the function (G.1) in equation (7). This parameter is given as follows.

$$\theta^L = \left[\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} b + b - 1\right]^{-1} \left[\left(p^L - p\right)\left(1 + \left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}}\right) - \left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} F\right] \tag{G.3}$$

Appendix H. The policy mix: a numerical application

This appendix completes the policy implications discussed in Section 6 with further explanations of the calibrations, as well as with sensitivity analyses of the *post-legalization* equilibrium to the behavioral and policy parameters.

The sensitivity analyses rely on comparisons with the benchmark scenario in which the model parameters are set at the values calibrated by Tversky and Kahneman (1992) and policy parameters are set at benchmark values $q_L = 0.1\%$, $F = 1{,}000$, $b = 1.58$, and $c = 50$, which yields the benchmark eviction price $\underline{p}^L = 97.79$, using the closed-form expression (18).

H.1. Calibration of the distribution of "taste" for cannabis

We calibrate the distribution of the "taste" for cannabis using our model and the literature on demand for cannabis, which estimates the range of price elasticities of demand, $\epsilon_{D^I p}$, between -0.5 and -0.8. Let us assume the "taste" for cannabis, $\theta \in \mathbb{R}$, is drawn from a normal distribution $\mathcal{N}(\mu, \sigma^2)$. The expression of the price elasticity of demand in equation (4) becomes

$$\epsilon_{D^I p} = \frac{p}{v}\left[\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} + 1\right] \frac{1}{\sigma\sqrt{2\pi}} \frac{e^{\frac{-(\theta^I-\mu)^2}{2\sigma^2}}}{1-\phi(\frac{\theta^I-\mu}{\sigma})} \tag{H.1}$$

In 2017, 15% of Americans are estimated to have used cannabis in the past year (Center for Behavioral Health Statistics and Quality, 2018). This margin is simply given by:

$$\varsigma = 1 - \phi\left(\frac{\theta^I - \mu}{\sigma}\right) \tag{H.2}$$

Using the estimates of ϵ and ς discussed in the literature, we calibrate the parameters μ and σ solving the system defined by equations (H.1) and (H.2), normalizing $v \equiv 1$ and using the benchmark values for the model parameters described in Section 6.1. Using an iterative solver, we obtain the set of solutions described in Table H.3 for μ and σ, as well as the benchmark values for the *post-legalization* increase in consumption implementing the eviction price $\underline{p}^L = 97.79$,[51] $\Delta D\left(\underline{p}^L\right)$. As the demand becomes more inelastic, the distribution tail becomes fatter and the mean taste lower. The more inelastic the demand, the lower the *post-legalization* increase in demand.

The sensitivity of the distribution parameters and of the predictions of the models to the behavioral parameters γ^+, γ^-, α and λ is discussed in Appendix H.2. This appendix also shows that small variations around the values calibrated by Tversky and Kahneman (1992) induce relatively little change in the predicted policy price $\underline{p}^L$ and subsequent increases in consumption.

[51] This eviction price assumes that, under legalization, the probability of arrest is ten times smaller ($q_L = 0.1\%$) than under prohibition ($q = 1\%$); and that the marginal cost on the black market is USD 50 *post-legalization*.

Table H.3
Distribution parameters and *post-legalization* increases in consumption.

$\epsilon_{D'p}$	$\hat{\mu}$	$\hat{\sigma}$	$\Delta D\left(\underline{p}^L\right)$
0.5	-690.4	1065.8	53%
0.6	-506.3	888.1	65%
0.7	-374.8	761.3	78%
0.8	-276.2	666.1	91%

Notes: Behavioral parameters are set based on Tversky and Kahneman (1992): $\lambda = 2.25$, $\alpha = 0.88$, $\gamma^+ = 0.61$, $\gamma^- = 0.69$. Variation in demand relies on the baseline estimate of $\underline{p}^L = 97.79$.

Table H.4
Sensitivity of eviction price and demand to behavioral parameters for $\epsilon = -0.5$.

parameter	variation	$\hat{\mu}$	$\hat{\sigma}$	$\underline{p}^L$	$\Delta D\left(\underline{p}^L\right)$
$\gamma^+ = 0.61$	+10%	0.1%	-0.22%	-0.21%	-0.3%
	+5%	0.06%	-0.12%	-0.12%	-0.16%
	-5%	-0.06%	0.15%	0.16%	0.2%
	-10%	-0.14%	0.33%	0.36%	0.46%
$\gamma^- = 0.69$	+10%	0.86%	-1.91%	-7.97%	-2.63%
	+5%	0.47%	-1.03%	-4.51%	-1.41%
	-5%	-0.53%	1.19%	5.86%	1.61%
	-10%	-1.15%	2.57%	13.45%	3.44%
$\alpha = 0.88$	+10%	-0.8%	1.8%	9.66%	2.43%
	+5%	-0.39%	0.89%	4.57%	1.21%
	-5%	0.39%	-0.87%	-4.04%	-1.18%
	-10%	0.77%	-1.7%	-7.54%	-2.33%
$\lambda = 2.25$	+10%	-0.33%	0.76%	2.2%	1.03%
	+5%	-0.16%	0.38%	1.1%	0.52%
	-5%	0.18%	-0.38%	-1.09%	-0.51%
	-10%	0.34%	-0.75%	-2.17%	-1.03%

Benchmark values in column 1 are $\hat{\mu} = -690.4$, $\hat{\sigma} = 1065.8$, $\underline{p}^L = 97.79$ and $\Delta D\left(\underline{p}^L\right) = 53.18\%$.

H.2. Sensitivity analysis of $\underline{p}^L$ to the behavioral parameters

Policy parameters are set at benchmark values $q_L = 0.1\%$, $F = 1{,}000$, $b = 1.58$, and $c = 50$. Prices and costs are for one ounce of cannabis. $\Delta D\left(\underline{p}^L\right)$ is the percentage predicted increase in consumption following a legalization process that drives dealers out of business.

We study the sensitivity of the eviction price, $\underline{p}^L$, to the exogenous behavioral parameters γ^+, γ^-, α and λ. The benchmark values are: $\alpha = 0.88$, $\lambda = 2.25$, $\gamma^+ = 0.61$ and $\gamma^- = 0.69$.

Tables H.4 to H.7 present in columns 3 and 4 the sensitivity of the distribution parameters, and in columns 5 and 6 the sensitivity of both the eviction price and the subsequent increase in consumption *post-legalization*. The magnitude of variations of the behavioral parameters around the benchmark values are presented in column 2.

Overall, the distribution parameters are not very sensitive to the variations in the behavioral parameters: variations in the behavioral parameters by 10% entail variations in the distribution parameters of less than 8% for most cases. The eviction price is fairly sensitive to the parameter γ^-: a 10% variation in this parameter causes a change in price of up to 13.5%. This is also true for the parameter α. Finally, *post-legalization* cannabis consumption is not very responsive to small variations in the behavioral parameters (by less than 10%) as it changes by less than 2% in most cases.

H.3. Sensitivity analysis to policy instruments

This section studies the sensitivity of the eviction price and of the *post-legalization* demand to parameters that can be influenced by policies. Several instruments are considered: reinforcing sanctions may increase the marginal cost of operations for illegal suppliers, c, the probability of arrest, q, or fines to illegal consumers, F. Moreover, investing in the quality of the legal cannabis, including the purchasing experience, taste of the product, certification of potency and of the healthiness of the production process, and information/education campaigns about the danger of consuming illegal cannabis will increase the relative valuation of consumption of legal cannabis, b. This aspect is generally overlooked by proponents of cannabis legalization. Yet our simulations show that it is an important instrument of any successful reform.

Table H.5
Sensitivity of eviction price and demand to behavioral parameters for $\epsilon = -0.6$.

parameter	variation	$\hat{\mu}$	$\hat{\sigma}$	$\underline{p}^L$	$\Delta D\left(\underline{p}^L\right)$
$\gamma^+ = 0.61$	+10%	0.22%	-0.21%	-0.21%	-0.34%
	+5%	0.13%	-0.12%	-0.12%	-0.19%
	-5%	-0.14%	0.15%	0.16%	0.24%
	-10%	-0.32%	0.34%	0.36%	0.53%
$\gamma^- = 0.69$	+10%	1.87%	-1.91%	-7.97%	-3.05%
	+5%	1.01%	-1.03%	-4.51%	-1.63%
	-5%	-1.16%	1.2%	5.86%	1.87%
	-10%	-2.5%	2.57%	13.45%	3.99%
$\alpha = 0.88$	+10%	-1.75%	1.81%	9.66%	2.82%
	+5%	-0.86%	0.9%	4.57%	1.4%
	-5%	0.85%	-0.86%	-4.04%	-1.37%
	-10%	1.66%	-1.69%	-7.54%	-2.7%
$\lambda = 2.25$	+10%	-0.73%	0.77%	2.2%	1.2%
	+5%	-0.36%	0.38%	1.1%	0.6%
	-5%	0.38%	-0.37%	-1.09%	-0.6%
	-10%	0.74%	-0.75%	-2.17%	-1.19%

Benchmark values in column 1 $\hat{\mu} = -506.3$, $\hat{\sigma} = 888.1$, $\underline{p}^L = 97.79$ and $\Delta D\left(\underline{p}^L\right) = 65.45\%$.

Table H.6
Sensitivity of eviction price and demand to behavioral parameters for $\epsilon = -0.7$.

parameter	variation	$\hat{\mu}$	$\hat{\sigma}$	$\underline{p}^L$	$\Delta D\left(\underline{p}^L\right)$
$\gamma^+ = 0.61$	+10%	0.37%	-0.22%	-0.21%	-0.39%
	+5%	0.21%	-0.12%	-0.12%	-0.21%
	-5%	-0.24%	0.14%	0.16%	0.27%
	-10%	-0.55%	0.33%	0.36%	0.6%
$\gamma^- = 0.69$	+10%	3.2%	-1.92%	-7.97%	-3.43%
	+5%	1.73%	-1.03%	-4.51%	-1.84%
	-5%	-1.98%	1.19%	5.86%	2.11%
	-10%	-4.27%	2.56%	13.45%	4.49%
$\alpha = 0.88$	+10%	-3.0%	1.8%	9.66%	3.17%
	+5%	-1.48%	0.89%	4.57%	1.58%
	-5%	1.45%	-0.87%	-4.04%	-1.54%
	-10%	2.84%	-1.7%	-7.54%	-3.03%
$\lambda = 2.25$	+10%	-1.26%	0.76%	2.2%	1.35%
	+5%	-0.62%	0.37%	1.1%	0.67%
	-5%	0.64%	-0.38%	-1.09%	-0.67%
	-10%	1.27%	-0.76%	-2.17%	-1.34%

Benchmark values in column 1 $\hat{\mu} = -374.8$, $\hat{\sigma} = 761.3$, $\underline{p}^L = 97.79$ and $\Delta D(\underline{p}^L) = 78.23\%$.

The first row of Table H.8 presents the benchmark values of the policy parameters in columns 1 to 4, as well as the resulting eviction legal price $\underline{p}^L$ around USD 98, and the resulting relative increase in the extensive margin of consumption *post-legalization* – which depends on the values of price elasticities of demand – in columns 5 to 8.

Rows 2 to 7 of Table H.8 present several scenarios regarding the marginal cost of operating on the black market. In the first scenario, the marginal cost for illegal production and distribution of cannabis drops to 15$ per ounce. This captures a situation in which controls are very lax and hence are not inflating the marginal cost of operation for illegal suppliers, which comes close to the estimates given by Caulkins (2010). We then present other cases where increasing and enforcing the sanctions against illegal producers and retailers raises the marginal cost of production on the black market up to 250$.

Another parameter whose evolution is hard to predict is b. Indeed, when retail sales for cannabis are legal, certified products appear, which is likely to increase b. Moreover, legalization decreases search costs, which also contributes to raising b. Meanwhile, being challenged by a newly legalized market, black-market producers and retailers may decide to invest in better products and services. For instance, some consumers may not want to be seen coming in person to a dispensary, due to social stigma or professional constraints that strictly forbid them to consume cannabis (in the case of truck drivers for example), and may turn to a black-market

Table H.7
Sensitivity of eviction price and demand to the behavioral parameters for $\epsilon = -0.8$.

parameter	variation	$\hat{\mu}$	$\hat{\sigma}$	$\underline{p}^L$	$\Delta D\left(\underline{p}^L\right)$
$\gamma^+ = 0.61$	+10%	0.58%	-0.22%	-0.21%	-0.42%
	+5%	0.32%	-0.12%	-0.12%	-0.23%
	-5%	-0.38%	0.15%	0.16%	0.29%
	-10%	-0.88%	0.34%	0.36%	0.66%
$\gamma^- = 0.69$	+10%	5.02%	-1.91%	-7.97%	-3.78%
	+5%	2.71%	-1.03%	-4.51%	-2.02%
	-5%	-3.12%	1.2%	5.86%	2.32%
	-10%	-6.72%	2.57%	13.45%	4.95%
$\alpha = 0.88$	+10%	-4.73%	1.81%	9.66%	3.5%
	+5%	-2.33%	0.89%	4.57%	1.74%
	-5%	2.27%	-0.86%	-4.04%	-1.7%
	-10%	4.44%	-1.69%	-7.54%	-3.34%
$\lambda = 2.25$	+10%	-1.99%	0.76%	2.2%	1.48%
	+5%	-0.99%	0.38%	1.1%	0.74%
	-5%	1.0%	-0.38%	-1.09%	-0.74%
	-10%	1.98%	-0.75%	-2.17%	-1.47%

Benchmark values in column 1 $\hat{\mu} = -276.2$, $\hat{\sigma} = 666.1$, $\underline{p}^L = 97.79$, $\Delta D(\underline{p}^L) = 91.49\%$.

Table H.8
Sensitivity of legalization price (in USD per ounce) and change in *post-legalization* demand (in percentage).

Policy parameters				Eviction price	Increase in demand			
c	b	q	F	$\underline{p}^L$	$\epsilon = -0.5$	$\epsilon = -0.6$	$\epsilon = -0.7$	$\epsilon = -0.8$
50	1.58	0.1%	1000	97.79	53%	65%	78%	92%
15	1.58	0.1%	1000	41.86	64%	79%	95%	111%
25	1.58	0.1%	1000	57.84	61%	75%	90%	105%
75	1.58	0.1%	1000	137.74	46%	56%	67%	78%
100	1.58	0.1%	1000	177.68	38%	47%	56%	65%
150	1.58	0.1%	1000	257.58	25%	30%	35%	41%
250	1.58	0.1%	1000	417.37	0%	-1%	-1%	-1%
50	0.50	0.1%	1000	30.95	66%	82%	98%	115%
50	0.75	0.1%	1000	46.42	63%	78%	93%	109%
50	1.00	0.1%	1000	61.89	60%	74%	89%	104%
50	2.00	0.1%	1000	123.78	48%	59%	71%	83%
50	3.00	0.1%	1000	185.68	37%	45%	54%	63%
50	1.58	0.0%	-	79.0	57%	70%	84%	98%
50	1.58	0.01%	1000	82.06	56%	69%	83%	97%
50	1.58	0.2%	1000	111.56	51%	62%	74%	87%
50	1.58	0.5%	1000	146.68	44%	54%	64%	75%
50	1.58	1.0%	1000	197.33	35%	43%	51%	59%
50	1.58	2.0%	1000	287.37	20%	24%	28%	33%
50	1.58	0.1%	500	88.84	55%	68%	81%	95%
50	1.58	0.1%	1500	106.74	52%	63%	76%	88%
50	1.58	0.1%	2000	115.68	50%	61%	73%	85%
50	1.58	0.1%	3000	133.58	46%	57%	68%	79%
50	1.58	0.1%	5000	169.37	40%	49%	58%	68%

Notes: Behavioral parameters are set at $\lambda = 2.25$, $\alpha = 0.88$, $\gamma^+ = 0.61$, and $\gamma^- = 0.69$ as estimated by Tversky and Kahneman (1992). Variation in demand relies on the baseline estimates for the parameters of the distribution of θ corresponding to different price elasticities of demand, as described in Table H.3.

delivery service. This may reduce the relative value of legal cannabis. Starting from our benchmark value, $b = 1.58$, rows 8 to 12 consider alternative cases, for b increasing to 3.00 or falling to 0.50.[52]

[52] H.4 discusses the case with $b < 1$.

Table H.9
Sensitivity analysis of eviction price and post-legalization demand.

Policy parameters				Eviction price	Increase in demand			
c	b	q	F	$\underline{p}^L$	$\epsilon = -0.5$	$\epsilon = -0.6$	$\epsilon = -0.7$	$\epsilon = -0.8$
50	1.58	0.1%	1000.0	97.79	53%	65%	78%	91%
15	2.00	0.05%	2000.0	56.39	61%	75%	90%	106%
25	2.00	0.05%	2000.0	76.52	57%	71%	84%	99%
100	2.00	0.05%	2000.0	227.5	30%	36%	43%	50%
200	2.00	0.05%	2000.0	428.81	-2%	-3%	-3%	-3%
50	1.00	0.05%	1000.0	56.88	61%	75%	90%	106%
50	1.25	0.05%	1000.0	71.09	58%	72%	86%	101%
50	1.58	0.05%	1000.0	89.86	55%	67%	81%	94%
50	2.00	0.05%	1000.0	113.75	50%	62%	74%	86%
50	3.00	0.05%	1000.0	170.63	40%	49%	58%	67%
50	4.00	0.05%	1000.0	227.5	30%	36%	43%	50%
50	1.58	0.05%	1000.0	89.86	55%	67%	81%	94%
50	1.58	0.1%	2000.0	115.68	50%	61%	73%	85%
50	1.58	0.05%	3000.0	110.55	51%	62%	75%	87%
50	1.58	0.2%	500.0	96.06	54%	66%	79%	92%
50	1.58	0.5%	5000.0	404.51	1%	2%	2%	2%
50	2.00	1.0%	2000.0	392.45	3%	4%	5%	5%
100	1.58	1.5%	1500.0	408.79	1%	1%	1%	1%
50	2.00	0.5%	4000.0	430.44	-2%	-3%	-3%	-4%
100	2.25	1.0%	1000.0	401.54	2%	2%	3%	3%
15	2.50	1.0%	2000.0	396.82	3%	3%	4%	4%
15	1.58	0.5%	6000.0	411.41	0%	0%	1%	1%
25	1.25	2.0%	2500.0	427.67	-2%	-2%	-3%	-3%
50	1.58	2.0%	1500.0	386.59	4%	5%	6%	7%
50	3.00	1.0%	1000.0	374.68	6%	7%	8%	9%
15	1.00	0%	-	15.0	69%	86%	103%	121%
25	1.00	0%	-	25.0	67%	83%	100%	117%
50	1.00	0%	-	50.0	62%	77%	92%	108%
75	1.00	0%	-	75.0	58%	71%	85%	99%
100	1.00	0%	-	100.0	53%	65%	78%	91%
125	1.00	0%	-	125.0	48%	59%	70%	82%

Notes: Behavioral parameters are set at values calibrated by Tversky and Kahneman (1992): $\lambda = 2.25$, $\alpha = 0.88$, $\gamma^+ = 0.61$, and $\gamma^- = 0.69$. Variation in demand relies on the baseline estimates for the parameters of the distribution of θ corresponding to different price elasticities of demand, as described in Table H.3.

Rows 13 to 18 vary the probability of being caught on the black market, q. Once a legal market is established, it may become more costly to detect consumers of illegal cannabis than it was under strict prohibition, such that q may decrease. On the other hand, it may be politically more feasible to be tough on consumers of illegal cannabis, such that q may increase. Rows 19 to 23 allow for several values of fines, F. For similar reasons, it may or may not be easier to implement higher fines with legalization, which is captured by the range of values chosen for the sensitivity analysis. In particular, it might be politically easier to implement higher fines when a legal alternative exists.

Response to the policy mix To illustrate how governments may use a combination of policy instruments to regulate the market for cannabis *post-legalization*, Table H.9 exploits combined variations in several policy parameters.

The first row presents the current benchmark values for the different policy parameters, the recommended legal price $\underline{p}^L$ and the *post-legalization* increase in the extensive margin of consumption.

Rows 2 to 5 present scenarios in which the government certifies the quality of legal cannabis, such that b goes up to 2, and does not invest a lot in detecting illegal purchases, such that the probability of arrest q is half the benchmark value, but doubles the fines for illegal purchase ($F = 2000$). At the same time it may choose or not to enforce repression against illegal providers, the marginal cost c varying from 15 – i.e. less than a third of the benchmark value – to 200 – i.e. four times the benchmark value. Simulations show that the government is able to contain consumption at the *pre-legalization* level when the marginal cost is four times the benchmark value ($c = 200$).

Rows 6 to 11 show that investing in quality differentiation (increasing b) is effective at reducing cannabis consumption. Even with lax enforcement of arrest of illegal users ($q = 0.05\%$), row 11 shows that limiting the consumption increase *post-legalization* can be achieved by investing in quality differentiation and certification of legal cannabis, such that $b = 4$.

Rows 12 to 16 show simulations of policies which increase repression on the demand side through various intensities of arrests q and fine amounts F, while the other parameters are kept at benchmark values. While increasing the level of fines seems to be an effective way to limit *post-legalization* consumption, high fines may be neither cost-effective nor fair, especially to low income users. Similarly, increased enforcement of arrests combined with statistical discrimination may also result in an uneven burden on some populations.

The fourth part of the table (rows 17 to 25) presents results where the *post-legalization* consumption is contained around the *pre-legalization* level. These results highlight that a government aiming at controlling cannabis consumption through legalization would have to invest in strict repression of either the supply or the demand side, as well as in product differentiation, certification and information campaigns. For instance, a legalization policy combined with significant investments in quality differentiation of legal cannabis ($b = 2$) and increased fines for illegal consumption up to USD 4000 would lead to the eviction price of USD 430 per ounce, decreasing cannabis consumption by 2.35% to 3.75%.

The last exercise illustrates an extreme case of no differentiation between legal and illegal products in a liberal state without repression on the demand and supply sides of the market, thus pricing legal cannabis at the marginal cost of production, which is the same on the illegal market. The absence of regulation results in large increases in *post-legalization* consumption, larger than 50% in most scenarios and more than 100% with large price elasticities of demand or low production costs.

H.4. On the existence of θ^L when $b < 1$

In the theory, for the sake of simplicity, we prove the existence and uniqueness of θ^L under the sufficient condition $b \geq 1$. However, this condition is not necessary.

Take the weighting and value functions calibrated in Tversky and Kahneman (1992), as well as $v = 1$. In this case,

$$\underline{p}^L = b\left[\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}}(F+c)+c\right],$$

while

$$\theta^L = \left[\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} b + b - 1\right]^{-1} \left[\left(\lambda \frac{w^-(q)}{w^+(1-q)}\right)^{\frac{1}{\alpha}} \left(p^L - p - F\right) + p^L - p\right];$$

which does not require that $b \geq 1$. For instance, when $c = 50$, $b = 0.5$, $q = 0.1\%$ and $F = 1000$, the legal price threshold $\underline{p}^L$ is around 31$ and $\theta^L\left(c, \underline{p}^L\right)$ exists and is unique – it is approximately equal to 61.89.

Appendix I. Maximizing tax revenues: a numerical application

This section provides detail on the tax policy application discussed in Section 5. It also presents the results for the other values of the price demand elasticity, as well as other examples, where there is very lax enforcement on the demand side of the market, leading to a probability of arrest close to zero, $q = 0$.

The methodology of this numerical exercise relies on the calibration results of Table H.3 and follows the same principle as in Section 6 and Appendix H. We use an iterative solver on the system of equations (15) and (10) with $p^L = (1+\tau)c^L$.

Table I.10 explores different scenarios in terms of enforcement and quality. The first column presents the *post-legalization* concentration on the illegal market. Using the Cournot optimality condition with the benchmark black-market price of USD 97.79 computed in Appendix H and marginal costs valued at USD 320 and USD 50 respectively, yields a concentration on the black market under prohibition of between 0.42 and 0.68, when the price demand elasticity varies between 0.5 and 0.8. We therefore chose 0.55 as a benchmark value for this parameter. Although the concentration on the black market is not a policy parameter *per se*, the legalization may generate changes in the concentration on the black market, which is why we study scenarios where this parameter varies from 0.10 to 1.00.

Columns 2 to 5 describe the values of the other policy parameters, whose notations are unchanged. Columns 6 and 7 provide the equilibrium prices on the black market and on the legal market, while columns 8 and 9 give the overall increase in demand $\Delta D(p, p^L)$, as well as the share of the black market in the total demand, $\% D^I$. Column 10 describes the tax revenue R in USD *per capita* and *per annum* derived from state cannabis sales for the specified price and demand on the legal market. The last three columns provide the eviction price, as well as the corresponding increase in demand and tax revenue in USD *per capita* and *per annum*.

We present, in Tables I.11 to I.13, the results of the numerical exercise from Section 5 for higher values of the demand price elasticity (-0.5, -0.6 and -0.7). As expected, the more inelastic the demand, the higher the equilibrium prices and the government revenue. Again we find that the price maximizing tax revenue is generally well above the eviction price (except when the quality is the same on both markets) and the corresponding extensive margins of consumption are of the same magnitude.

Table I.10
Legalization price and resulting demand when the government maximizes tax revenue ($\epsilon = -0.8$).

	Policy parameters				Equilibrium prices		Demand and revenue			Eviction scenario		
$\frac{1}{N}$	c	b	q	F	p	p^L	$\Delta D\left(p, p^L\right)$	$s^I\left(p, p^L\right)$	R	$\underline{p}^L$	$\Delta D\left(\underline{p}^L\right)$	$\underline{R}$
0.55	50	1.58	0.1%	1000	95.33	297.47	33%	35%	341	97.79	104%	151
0.55	25	1.58	0.1%	1000	78.60	292.94	29%	39%	320	57.84	113%	71
0.55	125	1.58	0.1%	1000	146.13	311.84	45%	18%	409	217.63	78%	350
0.55	200	1.58	0.1%	1000	200.42	338.15	54%	0%	491	337.47	54%	490
0.10	50	1.58	0.1%	1000	61.33	288.35	25%	44%	300	97.79	104%	151
0.25	50	1.58	0.1%	1000	75.15	292.01	28%	40%	316	97.79	104%	151
0.75	50	1.58	0.1%	1000	105.23	300.20	35%	32%	353	97.79	104%	151
1.00	50	1.58	0.1%	1000	115.05	302.94	37%	29%	366	97.79	104%	151
0.55	50	1.00	0.1%	1000	56.11	67.85	102%	0%	88	61.89	104%	77
0.55	50	1.10	0.1%	1000	55.20	84.04	76%	15%	103	68.08	104%	90
0.55	50	1.30	0.1%	1000	76.13	173.87	44%	31%	205	80.46	104%	115
0.55	50	1.80	0.1%	1000	105.56	393.40	28%	36%	443	111.41	104%	180
0.55	50	1.58	0.2%	1000	92.88	302.42	33%	33%	351	111.56	101%	177
0.55	50	1.58	0.5%	1000	86.81	314.70	36%	29%	377	146.68	93%	240
0.55	50	1.58	1.0%	1000	78.42	331.60	38%	23%	413	197.33	82%	320
0.55	50	1.58	0.0%	1000	98.73	290.60	31%	37%	327	79.00	108%	115
0.55	50	1.58	0.1%	100	98.65	295.63	31%	37%	333	81.68	108%	120
0.55	50	1.58	0.1%	500	97.17	296.45	32%	36%	336	88.84	106%	134
0.55	50	1.58	0.1%	1500	93.49	298.51	33%	34%	346	106.74	102%	168
0.55	50	1.58	0.1%	2000	91.66	299.55	34%	32%	350	115.68	100%	185

Notes: The above results are based on a price demand elasticity of 0.8 and the corresponding distribution parameters (see Table H.3). The marginal cost on the legal market, c^L, is USD 25 per ounce. The tax revenue in USD *per capita* and *per annum* is given as the product of the difference $p^L - c^L$ with the extensive and intensive margins of consumption. The intensive margin is approximated using Orens et al. (2018) estimates for consumption in Colorado in 2017.

Table I.11
Legalization price and resulting demand when the government maximizes tax revenue ($\epsilon = -0.7$).

	Policy parameters				Equilibrium prices		Equilibrium demand and revenue			Eviction scenario		
$\frac{1}{N}$	c	b	q	F	p	p^L	$\Delta D\left(p, p^L\right)$	$s^I\left(p, p^L\right)$	R	$\underline{p}^L$	$\Delta D\left(\underline{p}^L\right)$	$\underline{R}$
0.55	50	1.58	0.1%	1000	101.78	325.65	21%	36%	342	97.79	89%	140
0.55	25	1.58	0.1%	1000	85.11	321.32	18%	40%	323	57.84	96%	66
0.55	125	1.58	0.1%	1000	152.34	339.28	31%	21%	403	217.63	67%	328
0.55	200	1.58	0.1%	1000	203.66	353.91	42%	3%	473	337.47	47%	467
0.10	50	1.58	0.1%	1000	62.98	315.69	14%	45%	300	97.79	89%	140
0.25	50	1.58	0.1%	1000	78.78	319.69	17%	42%	316	97.79	89%	140
0.75	50	1.58	0.1%	1000	113.04	328.62	23%	33%	355	97.79	89%	140
1.00	50	1.58	0.1%	1000	124.19	331.60	25%	30%	368	97.79	89%	140
0.55	50	1.00	0.1%	1000	57.06	69.03	87%	0%	84	61.89	89%	71
0.55	50	1.10	0.1%	1000	56.88	89.07	58%	18%	100	68.08	89%	83
0.55	50	1.30	0.1%	1000	80.38	188.68	31%	32%	204	80.46	89%	107
0.55	50	1.80	0.1%	1000	113.15	431.97	17%	37%	445	111.41	89%	166
0.55	50	1.58	0.2%	1000	99.34	330.90	22%	34%	351	111.56	86%	164
0.55	50	1.58	0.5%	1000	93.27	343.94	23%	31%	376	146.68	80%	223
0.55	50	1.58	1.0%	1000	84.87	361.86	25%	26%	409	197.33	71%	299
0.55	50	1.58	0.0%	1000	105.18	318.35	20%	38%	328	79.00	92%	106
0.55	50	1.58	0.1%	100	105.13	323.89	20%	37%	334	81.68	92%	111
0.55	50	1.58	0.1%	500	103.64	324.67	20%	37%	337	88.84	90%	124
0.55	50	1.58	0.1%	1500	99.93	326.63	22%	35%	346	106.74	87%	156
0.55	50	1.58	0.1%	2000	98.08	327.62	22%	34%	350	115.68	85%	171

Notes: The above results are based on a price demand elasticity of 0.7 and the corresponding distribution parameters (see Table H.3). The marginal cost on the legal market, c^L, is USD 25 per ounce. The tax revenue in USD *per capita* and *per annum* is given as the product of the difference $p^L - c^L$ with the extensive and intensive margins of consumption. The intensive margin is approximated using Orens et al. (2018) estimates for consumption in Colorado in 2017.

Table I.12
Legalization price and resulting demand when the government maximizes tax revenue ($\epsilon = -0.6$).

	Policy parameters				Equilibrium prices		Equilibrium demand and revenue			Eviction scenario		
$\frac{1}{N}$	c	b	q	F	p	p^L	$\Delta D(p, p^L)$	$s^I(p, p^L)$	R	$\underline{p}^L$	$\Delta D(\underline{p}^L)$	$\underline{R}$
0.55	50	1.58	0.1%	1000	110.50	363.72	10%	37%	348	97.79	74%	129
0.55	25	1.58	0.1%	1000	93.89	359.59	7%	41%	331	57.84	80%	60
0.55	125	1.58	0.1%	1000	160.82	376.65	18%	24%	403	217.63	56%	306
0.55	200	1.58	0.1%	1000	211.81	390.40	26%	9%	464	337.47	39%	443
0.10	50	1.58	0.1%	1000	65.21	352.61	3%	47%	304	97.79	74%	129
0.25	50	1.58	0.1%	1000	83.68	357.08	6%	43%	321	97.79	74%	129
0.75	50	1.58	0.1%	1000	123.60	367.03	12%	34%	362	97.79	74%	129
1.00	50	1.58	0.1%	1000	136.54	370.34	14%	30%	376	97.79	74%	129
0.55	50	1.00	0.1%	1000	51.86	63.69	74%	0%	68	61.89	74%	65
0.55	50	1.10	0.1%	1000	59.24	96.04	41%	21%	98	68.08	74%	76
0.55	50	1.30	0.1%	1000	86.15	208.78	18%	33%	206	80.46	74%	98
0.55	50	1.80	0.1%	1000	123.41	484.03	6%	38%	454	111.41	74%	153
0.55	50	1.58	0.2%	1000	108.07	369.42	10%	36%	357	111.56	72%	152
0.55	50	1.58	0.5%	1000	102.03	383.54	12%	32%	380	146.68	67%	207
0.55	50	1.58	1.0%	1000	93.64	402.94	13%	28%	412	197.33	59%	279
0.55	50	1.58	0.0%	1000	113.88	355.81	9%	38%	335	79.00	77%	97
0.55	50	1.58	0.1%	100	113.87	362.05	9%	38%	341	81.68	77%	102
0.55	50	1.58	0.1%	500	112.38	362.79	9%	38%	344	88.84	75%	114
0.55	50	1.58	0.1%	1500	108.64	364.66	10%	36%	352	106.74	73%	144
0.55	50	1.58	0.1%	2000	106.77	365.60	11%	35%	356	115.68	71%	158

Notes: The above results are based on a price demand elasticity of 0.6 and the corresponding distribution parameters (see Table H.3). The marginal cost on the legal market, c^L, is USD 25 per ounce. The tax revenue in USD *per capita* and *per annum* is given as the product of the difference $p^L - c^L$ with the extensive and intensive margins of consumption. The intensive margin is approximated using Orens et al. (2018) estimates for consumption in Colorado in 2017.

Table I.13
Legalization price and resulting demand when the government maximizes tax revenue ($\epsilon = -0.5$).

	Policy parameters				Equilibrium prices		Equilibrium demand and revenue			Eviction scenario		
$\frac{1}{N}$	c	b	q	F	p	p^L	$\Delta D(p, p^L)$	$s^I(p, p^L)$	R	$\underline{p}^L$	$\Delta D(\underline{p}^L)$	$\underline{R}$
0.55	50	1.58	0.1%	1000	122.89	417.78	-1%	38%	363	97.79	60%	119
0.55	25	1.58	0.1%	1000	106.32	413.84	-3%	41%	348	57.84	65%	55
0.55	125	1.58	0.1%	1000	172.96	430.04	5%	27%	412	217.63	46%	286
0.55	200	1.58	0.1%	1000	223.61	442.94	12%	15%	466	337.47	32%	421
0.10	50	1.58	0.1%	1000	68.37	404.99	-7%	48%	315	97.79	60%	119
0.25	50	1.58	0.1%	1000	90.64	410.15	-5%	44%	334	97.79	60%	119
0.75	50	1.58	0.1%	1000	138.60	421.58	1%	35%	378	97.79	60%	119
1.00	50	1.58	0.1%	1000	154.09	425.36	3%	31%	393	97.79	60%	119
0.55	50	1.00	0.1%	1000	53.11	65.03	59%	0%	65	61.89	60%	60
0.55	50	1.10	0.1%	1000	62.68	106.11	25%	24%	99	68.08	60%	70
0.55	50	1.30	0.1%	1000	94.38	237.41	7%	35%	213	80.46	60%	90
0.55	50	1.80	0.1%	1000	137.95	557.87	-4%	39%	475	111.41	60%	141
0.55	50	1.58	0.2%	1000	120.48	424.13	-1%	37%	372	111.56	58%	140
0.55	50	1.58	0.5%	1000	114.49	439.87	0%	34%	394	146.68	54%	191
0.55	50	1.58	1.0%	1000	106.15	461.47	2%	30%	424	197.33	48%	260
0.55	50	1.58	0.0%	1000	126.22	408.95	-2%	39%	351	79.00	62%	89
0.55	50	1.58	0.1%	100	126.28	416.18	-2%	39%	357	81.68	62%	94
0.55	50	1.58	0.1%	500	124.77	416.89	-1%	39%	360	88.84	61%	105
0.55	50	1.58	0.1%	1500	121.01	418.68	-1%	37%	367	106.74	59%	132
0.55	50	1.58	0.1%	2000	119.13	419.57	0%	36%	370	115.68	58%	146

Notes: The above results are based on a price demand elasticity of 0.5 and the corresponding distribution parameters (see Table H.3). The marginal cost on the legal market, c^L, is USD 25 per ounce. The tax revenue in USD *per capita* and *per annum* is given as the product of the difference $p^L - c^L$ with the extensive and intensive margins of consumption. The intensive margin is approximated using Orens et al. (2018) estimates for consumption in Colorado in 2017.

Table I.14
Legalization price and resulting demand when the government maximizes tax revenue and $q = 0$, for $\epsilon = -0.8$.

	Policy parameters		Equilibrium prices		Equilibrium demand and revenue			Eviction scenario		
$\frac{1}{N}$	c	b	p	p^L	$\Delta D\left(p, p^L\right)$	$s^I\left(p, p^L\right)$	R	$\underline{p}^L$	$\Delta D\left(\underline{p}^L\right)$	$\underline{R}$
0.55	50	1.58	98.73	290.60	91%	37%	327	79.0	108%	115
0.55	25	1.58	82.06	286.12	97%	41%	307	39.5	117%	32
0.55	125	1.58	149.39	304.83	74%	21%	393	197.5	82%	320
0.55	200	1.58	200.96	320.27	58%	1%	471	316.0	58%	469
0.10	50	1.58	62.22	280.90	104%	47%	284	79.0	108%	115
0.25	50	1.58	77.08	284.80	99%	43%	301	79.0	108%	115
0.75	50	1.58	109.34	293.51	88%	34%	340	79.0	108%	115
1.00	50	1.58	119.85	296.42	84%	31%	353	79.0	108%	115
0.55	50	1.01	56.78	57.33	106%	0%	68	50.5	108%	54
0.55	50	1.10	57.17	76.48	106%	22%	84	55.0	108%	64
0.55	50	1.30	78.97	166.77	98%	34%	189	65.0	108%	85
0.55	50	1.80	109.22	386.64	88%	38%	429	90.0	108%	138

Notes: The above results are based on a price demand elasticity of 0.8 and the corresponding distribution parameters (see Table H.3). The marginal cost on the legal market, c^L, is USD 25 per ounce. The tax revenue in USD *per capita* and *per annum* is given as the product of the difference $p^L - c^L$ with the extensive and intensive margins of consumption. The intensive margin is approximated using Orens et al. (2018) estimates for consumption in Colorado in 2017.

Table I.15
Legalization price and resulting demand when the government maximizes tax revenue and $q = 0$, for $\epsilon = -0.7$.

	Policy parameters		Equilibrium prices		Equilibrium demand and revenue			Eviction scenario		
$\frac{1}{N}$	c	b	p	p^L	$\Delta D\left(p, p^L\right)$	$s^I\left(p, p^L\right)$	R	$\underline{p}^L$	$\Delta D\left(\underline{p}^L\right)$	$\underline{R}$
0.55	50	1.58	105.18	318.35	76%	38%	328	79.0	92%	106
0.55	25	1.58	88.56	314.06	81%	42%	310	39.5	100%	30
0.55	125	1.58	155.60	331.86	62%	23%	388	197.5	70%	300
0.55	200	1.58	206.85	346.39	48%	6%	457	316.0	50%	445
0.10	50	1.58	63.87	307.84	88%	48%	284	79.0	92%	106
0.25	50	1.58	80.71	312.06	83%	44%	302	79.0	92%	106
0.75	50	1.58	117.13	321.48	73%	34%	342	79.0	92%	106
1.00	50	1.58	128.96	324.63	69%	31%	356	79.0	92%	106
0.55	50	1.01	55.18	55.71	91%	0%	60	50.5	92%	50
0.55	50	1.10	58.78	81.12	90%	24%	82	55.0	92%	59
0.55	50	1.30	83.18	181.16	82%	35%	189	65.0	92%	78
0.55	50	1.80	116.83	424.77	73%	39%	432	90.0	92%	127

Notes: The above results are based on a price demand elasticity of 0.7 and the corresponding distribution parameters (see Table H.3). The marginal cost on the legal market, c^L, is USD 25 per ounce. The tax revenue in USD *per capita* and *per annum* is given as the product of the difference $p^L - c^L$ with the extensive and intensive margins of consumption. The intensive margin is approximated using Orens et al. (2018) estimates for consumption in Colorado in 2017.

Table I.16
Legalization price and resulting demand when the government maximizes tax revenue and $q = 0$, for $\epsilon = -0.6$.

	Policy parameters		Equilibrium prices		Equilibrium demand and revenue			Eviction scenario		
$\frac{1}{N}$	c	b	p	p^L	$\Delta D\left(p, p^L\right)$	$s^I\left(p, p^L\right)$	R	$\underline{p}^L$	$\Delta D\left(\underline{p}^L\right)$	$\underline{R}$
0.55	50	1.58	113.88	355.81	62%	38%	335	79.0	77%	97
0.55	25	1.58	97.31	351.71	66%	42%	319	39.5	83%	27
0.55	125	1.58	164.07	368.64	50%	26%	389	197.5	59%	280
0.55	200	1.58	214.98	382.30	39%	11%	450	316.0	42%	421
0.10	50	1.58	66.10	344.17	73%	49%	289	79.0	77%	97
0.25	50	1.58	85.61	348.86	68%	45%	308	79.0	77%	97
0.75	50	1.58	127.66	359.27	58%	35%	350	79.0	77%	97
1.00	50	1.58	141.27	362.73	55%	32%	364	79.0	77%	97
0.55	50	1.01	53.56	54.08	76%	0%	52	50.5	77%	46
0.55	50	1.10	61.00	87.50	74%	26%	82	55.0	77%	54
0.55	50	1.30	88.87	200.65	68%	36%	192	65.0	77%	72
0.55	50	1.80	127.09	476.21	59%	39%	442	90.0	77%	117

Notes: The above results are based on a price demand elasticity of 0.6 and the corresponding distribution parameters (see Table H.3). The marginal cost on the legal market, c^L, is USD 25 per ounce. The tax revenue in USD *per capita* and *per annum* is given as the product of the difference $p^L - c^L$ with the extensive and intensive margins of consumption. The intensive margin is approximated using Orens et al. (2018) estimates for consumption in Colorado in 2017.

Table I.17
Legalization price and resulting demand when the government maximizes tax revenue and $q = 0$, for $\epsilon = -0.5$.

	Policy parameters		Equilibrium prices		Equilibrium demand and revenue			Eviction scenario		
$\frac{1}{N}$	c	b	p	p^L	$\Delta D(p, p^L)$	$s^I(p, p^L)$	R	$\underline{p}^L$	$\Delta D(\underline{p}^L)$	$\underline{R}$
0.55	50	1.58	126.22	408.95	48%	39%	351	79.0	62%	89
0.55	25	1.58	109.70	405.04	51%	43%	336	39.5	67%	25
0.55	125	1.58	176.18	421.13	39%	29%	399	197.5	48%	260
0.55	200	1.58	226.76	433.97	30%	16%	452	316.0	34%	399
0.10	50	1.58	69.26	395.67	59%	50%	302	79.0	62%	89
0.25	50	1.58	92.55	401.03	54%	46%	321	79.0	62%	89
0.75	50	1.58	142.60	412.89	45%	36%	366	79.0	62%	89
1.00	50	1.58	158.75	416.82	42%	33%	382	79.0	62%	89
0.55	50	1.01	53.84	54.37	62%	0%	48	50.5	62%	42
0.55	50	1.10	64.21	96.67	60%	29%	83	55.0	62%	50
0.55	50	1.30	96.96	228.35	53%	37%	200	65.0	62%	66
0.55	50	1.80	141.64	549.15	45%	40%	463	90.0	62%	108

Notes: The above results are based on a price demand elasticity of 0.5 and the corresponding distribution parameters (see Table H.3). The marginal cost on the legal market, c^L, is USD 25 per ounce. The tax revenue in USD *per capita* and *per annum* is given as the product of the difference $p^L - c^L$ with the extensive and intensive margins of consumption. The intensive margin is approximated using Orens et al. (2018) estimates for consumption in Colorado in 2017.

Results with $q = 0$ Tables I.14 to I.17 detail scenarios where consumers going to the illegal market are not arrested. Since the case where $b = 1$ and $q = 0$ yields perfect competition between the legal and the illegal markets, we prefer to present a case where there is very little quality differentiation ($b = 1.01$), rather than no differentiation. When there are no arrests on the demand side, individuals are all the more sensitive to quality. For a government maximizing tax revenue, quality has a large influence on the optimal price: when the quality differential is 1.01, the legal market price, p^L, is between USD 54 and 57 per ounce, depending on the elasticity; when $b = 1.80$, it rises up to USD 387 to 549.

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