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Bringing perspective to illicit markets: Estimating the size of the U.S. marijuana market☆

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ABSTRACT

Having a sense of the scale of an illicit drug market is important for projecting consequences of alternative policy regimes. In this article, we review two general approaches to drug market estimation – supply-side and demand-side – before turning to a more specific analysis of studies that measure the size of the U.S. marijuana market. The paper then generates a demand-side estimate of U.S. marijuana consumption for 2009 and shows how variation in assumptions such as grams per joint and extent of underreporting can cause substantial variation in estimates of market size. While both demand-side and supply-side estimates have weaknesses, the paper argues that the former are more promising for marijuana and offers suggestions on how to reduce the uncertainties surrounding them.

1. Introduction

A sense of scale is a prerequisite to thinking sensibly about illicit drug markets. For example, knowing whether a country consumes tens, hundreds, or thousands of metric tons (MT) of a prohibited substance is critical for understanding the impact of a 5 MT seizure at a border crossing.

Having a sense of scale is especially important for projecting consequences of alternative policy regimes. Any estimate of potential tax revenue from legalizing production and sales has to start with an estimate of the current market size. An understanding of the size of the market is also needed to estimate the costs of regulating the "newly legal" market, employment levels in the newly legal production industry, and a host of other relevant outcomes including what a given percentage change in use or dependence would imply for hours of intoxication or people in need of treatment.

Of late, there has been a great deal of discussion about legalizing marijuana, especially in the United States. Various analysts have published estimates of the size of the U.S. marijuana market, but the resulting figures differ by a factor of 10. The variation can be attributed to differences in methodologies, differences in assumptions, and to egregious errors caused by believing in "mythical numbers" – numbers that have no true empirical basis but nonetheless acquire great authority through sheer repetition and then often persist even in the face of contrary evidence (Singer, 1971; Reuter, 1984).

In this article, we review the two general approaches to estimating the size of drug markets – supply-side and demand-side – before turning to a more specific analysis of the studies that use these methods for informing estimates of the U.S. marijuana market. Then using a demand-side approach, the paper estimates U.S. marijuana consumption for 2009 and shows how variation in assumptions such as grams per joint and extent of underreporting can cause substantial variation in estimates of the size of the market. While both demand-side and supply-side estimates have weaknesses, the paper argues that the former are more promising and offers suggestions on how to reduce the uncertainties surrounding them.

2. Taxonomy of drug market estimation strategies

There are four general approaches for estimating the size of an illicit drug market. On the supply-side there are *production-based* and *seizure-based* estimates, while on the demand-side, there are *consumption-based* and *expenditure-based* estimates. Their contrasting strengths and weaknesses play out differently for different substances, making it important to choose the right method for the right drug market.

2.1. Supply-side estimation strategies

Production-based estimates for drugs derived from plants are grounded in the amount of land used to grow the drug crop and in estimates of yield (e.g., dry coca leaf per hectare for cocaine). Depending on the drug and location, land estimates

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can come from satellite or aerial photography, ground observations, or interviews. Yield estimates consider the average yield per plant, the number of harvests per year, and various conversion factors (e.g., dry weight per unit weight harvested). The product of multiplying hectares and yield is often combined with data about eradication to generate a figure known as "potential production." Multiplying by some assumption, which is often arbitrary, about the share of potential production that is successfully exported to a particular destination country and then subtracting domestic seizures made within that country yields an estimate of total consumption in that destination country.

While there are a number of problems when estimating cocaine and heroin production, such problems pale in comparison with those confronting production-based estimates of marijuana.[1] For one thing, substantial production in the United States, Canada, and Western Europe occurs indoors, while that which occurs outdoors is scattered across much of the country, rather than concentrated in clusters such as the Jungas in Bolivia for coca or Helmand in Afghanistan for poppy. Thus, aerial or satellite photography is virtually useless. Furthermore, as discussed below, there is also huge uncertainty about yield.

Seizure-based estimates simply divide total seizures over a year by some assumed proportion of shipments or plants that are seized or eradicated (e.g., 10%). While this approach is easy to implement, it is unsettling, because no one has a systematic basis for estimating the seizure rate. Furthermore, seizures are not merely proportional to production. Seizures also depend on law enforcement efforts and the care taken by growers and traffickers to protect their products (Reuter, 1995). They can also produce perverse results in policy analysis. For example, if enforcement agencies improve their performance and seize more of a drug, analysts using these methods will infer that the production and the production net of seizures (i.e., consumption) have gone up, not down. Thus, any attempt to determine which period's enforcement strategies had the most effect on reducing consumption would draw precisely the wrong conclusions.

2.2. *Demand-side estimation strategies*

Consumption-based estimates start with counts of the numbers of people who consume drugs with various frequencies or intensities of use (e.g., occasional and hard-core; or daily, weekly, and past-year) and multiply those counts by average rates of consumption, as measured by weight or "doses." In some studies, adjustments to the number of consumers are made to account for underreporting in surveys, as is done for estimates of legal intoxicants, such as alcohol (Cook, 2007).

Expenditure-based estimates combine user counts with estimates of annual amounts spent on drugs, rather than amounts consumed. An advantage of this approach is that although users generally do not know the exact quantity of drug that they bought, let alone its purity or potency, they often do know how much they spent for the purchase. These data are then combined with (purity-adjusted) price per unit weight to generate an estimate of the weight consumed. While this approach has been used for estimating the amount of cocaine and heroin consumed in the United States (Abt Associates, 2001), we are not aware of attempts to use it to estimate the size of the marijuana market.

[1] Bouchard's (2008) use of capture-recapture models to estimate the size of the marijuana cultivation industry in Quebec is one of the few recent innovations in production-based estimation.

3. Estimates of the U.S. marijuana market and their limitations

Estimates of the U.S. marijuana market are informed by both supply-side (based on marijuana production in the United States and in Mexico, the nation's main external supplier[2]) and demand-side approaches (U.S. consumption of marijuana). This section reviews the more serious estimates and their limitations. We conclude by calculating a demand-side estimate of U.S. marijuana consumption for 2009 and demonstrating how variation in some assumptions causes substantial variation in estimates of the size of the market.

3.1. *Marijuana production in the United States*

The claim that U.S. marijuana production reaches or exceeds 10,000 MT appears prominently in policy debates. As Gettman (2006) notes, this figure appears in numerous official national and international reports, including the 2002, 2003, and 2005 *International Narcotics Control Strategy Report* (INCSR), the 2003 *National Drug Control Strategy* (NCDS), and the United Nation's *Global Illicit Drug Trends, 2003* and the *2004 World Drug Report*. However, there are no sources for the INCSR or for the NDCS figures, and the UN documents reference the 2003 INCSR and 2003 NDCS. Thus, the 10,000 MT figure appears to be an example of a mythical number that achieved credence through repetition, not because of its research base (Singer, 1971; Reuter, 1984).

However, the figure may have its origins in a report published in 2002 by the Drug Availability Steering Committee (DASC),[3] which is chaired by the Drug Enforcement Administration (DEA) and includes representatives from other law enforcement agencies. Here we highlight the weaknesses of this estimate, but we also stress that DASC explicitly acknowledged those weaknesses.[4] For example, while DASC expressed some confidence in its cocaine estimates, with respect to U.S. marijuana production, it stated:

> The quantity of domestically produced marijuana that was available in the United States in 2001 is unknown. While the group did develop a methodology for determining such availability in the future, the uncertainty in the required data, some of which do not currently exist, is magnified by the model, and prevents the derivation of a credible estimate at this time. However, by making reasonable assumptions regarding the number of cannabis plants eradicated and the amount of marijuana potentially produced per cannabis plant, and applying a set of hypothetical values for the cannabis eradication rate, the model yields an estimate for the availability of domestic marijuana ranging between 5577 and 16,731 metric tons (p. 103).

The DASC estimates are reproduced in Table 1. DASC's 5577 MT figure combines plants eradicated (4,150,173) with assumptions that one marijuana plant yields one pound (448 g) of

[2] While estimates of production in other countries that supply marijuana to the U.S. (e.g., Canada and Jamaica) would be interesting, these markets generate a very small share of the marijuana provided to the U.S. market (c.f., Kilmer et al., 2010). Uncertainty about production in the U.S. and Mexico is far more impactful on overall estimates of the size of the U.S. market than is the omission of these additional production estimates.

[3] Since the 2002 INCSR report was published in 2003, it could have been influenced by the DASC report.

[4] Indeed, the DASC (2002) report is an exemplar of sensible analysis that was sensitive to its own limitations; the world of drug policy would be better informed if all government reports matched its integrity in this regard. Our criticism is not with the original authors, but rather with the unthinking repetition and acceptance of the figure.

Table 1
DASC estimates of domestically produced marijuana potentially available in the united states (in metric tons).

Assumed yield per plant	Hypothetical eradication rate		
	10%	15%	25%
200 g	7470	4703	2490
448 g (~1 pound)	16,731	10,534	5577
1 kilo	37,350	23,516	12,450

Notes: Reproduced from DASC (2002), Table 4-2, p. 107.

consumable product annually and that 25 percent of all domestically produced marijuana is seized (5577 MT = 4.15 million plants × 448 × (1 − 25%)/25%). The 16,731 MT figure is obtained by reducing the seizure rate to 10%. There is little agreement on the yield of a typical marijuana plant (Bouchard, 2008; Caulkins, 2010), so DASC also displays net production figures for per plant yields of 200 grams and 1 kilo.[5]

DASC did not intend these figures to be used for policy analysis; they were simply meant to illustrate how the calculations would work *if* the relevant parameters were known. Indeed, DASC explicitly describes the seizure rate thus: "There is currently no basis upon which to derive a credible estimate of the effectiveness of domestic cannabis eradication efforts. The figure is **unknown**" (emphasis in original; p. 116). Further highlighting the uncertainty is a memorandum at the end of the DASC report from the DEA's Statistical Services Unit with a list of alternative estimates about marijuana availability. After accounting for eradication, this memorandum states that net marijuana production in the United States was 2355 MT – far lower than the oft-reported 10,000 MT and lower than any of the estimates in the DASC table.

Nevertheless, this 10,000 MT figure features prominently in policy debates, notably including claims that marijuana is a leading cash crop. For example, during California's marijuana legalization debate, it was often reported that California produces $14 billion worth of marijuana each year. This $14 billion figure was cited in a California's Board of Equalization report (2009) and by the official ballot argument of Proposition 19's proponents (California Secretary of State, 2010).

However, Gettman (2006) produced the $14 billion figure by multiplying the 10,000 MT estimate, which he traces to DASC, by $1606 per pound and prorating across states in proportion to the number of plants eradicated in each state (separately for indoor and outdoor, and then combining). So, the idea that California growers earn $14 billion annually from production is predicated directly on this 10,000 MT estimate, whose own authors called it a "hypothetical" and meant only to illustrate how the arithmetic would be done if certain unknown parameters were to become known at some point in the future. Unfortunately, there appears to be little effort to produce an updated official estimate by any government agencies.

3.2. *Marijuana production in Mexico*

The majority of the marijuana consumed in the U.S. is imported, primarily from Mexico (Kilmer et al., 2010).[6] Unfortunately, U.S. government estimates of Mexican marijuana production published in the International Narcotics Control and Strategy Reports (INCSR) have long been inconsistent and at times implausible.

Reuter (1996) documented the "fundamental unsoundness" of the estimates from the late 1980s. Notably, the 1990 INCSR Report (U.S. Department of State, 1990) showed an increase in Mexican marijuana production from 5700 MT in 1988 to 47,000 MT in 1989 because of "changes in estimation techniques," without explaining what the changes were. (Likewise, no explanation was given for why the 1994 INCSR later reduced the 1989 figure from 47,000 MT to a still-high 30,200 MT.) After another aberrant year (19,700 MT in 1990), the estimates returned to more plausible values, beginning with 7775 MT in 1991 (U.S. Department of State, 1994).

The Mexican production estimates remained between 5300 and 11,300 MT for 15 years before rising sharply, again without a convincing explanation. While INCSR's supply-side estimates suggest that net production in Mexico almost tripled between 2001 and 2008 (from 7400 MT to 21,500 MT), we show in Table 2 that the number of current (meaning past-month) users in the United States remained stable at 15 million during that period. This raises important questions for those who accept the INCSR estimates at face value about where all this marijuana was going, because there is no evidence to suggest that the excess production was consumed in Mexico or other Latin American countries. Further, marijuana seizures at the border cannot account for the discrepancy – such seizures have hovered between 1000 and 1500 MT annually for most of the past decade (GAO, 2007; NDIC, 2010).

Table 2 also presents another example of how one agency can provide very different numbers over time. Data from the 2009 World Drug Report (WDR) (UNODC, 2009) imply that Mexican production was almost halved between 2007 and 2008, going from 27,806 to 15,800. UNODC is not fully responsible for these differences, because it depends on data provided to it by member states, but more could be done to help researchers and policymakers understand how confident they should be in these figures.

Now consider a rough calculation of what the 2010 INCSR or WDR figure of 21,500 MT produced in 2008 would imply for U.S. consumption. After subtracting Mexican and Southwest Border seizures in that year (1658 and 1253 MT, respectively), we end up with 18,589 MT; given the split in proportion to their respective number of past-year users (10% in Mexico/90% in the United States), this would suggest that U.S. consumption of Mexican marijuana is 16,730 MT (90% × 18,589 MT), or a total consumption of 25,100 MT if one believes the 2006 WDR estimate that one-third of the U.S. marijuana market is supplied domestically (16,730 MT/(1 − 33.3%)).

Comparisons with U.S. prevalence data suggest that existing estimates of Mexican marijuana production lack credibility. Specifically, even if we ignore imports from Canada, Jamaica, and elsewhere, allow 20% underreporting for past-month users in the National Survey on Drug Use and Health (NSDUH) (whose results for 2008 – 15.2 million – are shown in Table 2), and recognize that past-month users account for 88% of reported past-year days of marijuana use, that combination suggests that, on average, those past-month users were each consuming about 1.2 kilograms (kg)

[5] DASC observes about yield estimates: "There is no single agreed upon estimate for the average quantity of marijuana that can be produced from a single cannabis plant. The Royal Canadian Mounted Police uses an estimate of 170–200 g per plant in estimating marijuana production in Canada. DEA uses an estimate of approximately 1 pound (448 g) per plant based on a University of Mississippi study published in June 1992 and the USFS uses an estimate of 1 kilogram."

[6] Based on a review of national and international documents, reports from local DEA offices, and an analysis of marijuana price information from general population and arrestee surveys, Kilmer et al. (2010) suggest that between 40–67% of the marijuana consumed in the United States comes from Mexico. With smaller amounts of marijuana imported into the United States from Canada, Jamaica, and elsewhere, we believe that the majority of marijuana consumed in the U.S. is imported, with most coming from Mexico.

Table 2
Net marijuana production in Mexico and U.S. marijuana consumption.

Year	Potential *net* production of cannabis in Mexico (MT)			Past-month U.S. marijuana users (millions)	Percentage of 12th graders reporting daily marijuana use in previous month
	2010 INCSR	2009 WDR[a]	2010 WDR[b]	2002–2009 NSDUH[c]	2002–2010 MTF[d]
2001	7400			[e]	5.8
2002	7900			14.6	6.0
2003	13,500			14.6	6.0
2004	10,440			14.6	5.6
2005	10,100			14.6	5.0
2006	15,500			14.8	5.0
2007	15,800	27,806		14.5	5.1
2008	21,500	15,800	21,500	15.2	5.4
2009	N/A	N/A	N/A	16.7	5.2
2010	N/A	N/A	N/A	N/A	6.1

Notes: WDR: *World Drug Report*; NSDUH: National Survey on Drug Use and Health; MTF: Monitoring the Future.
[a] UNODC (2009).
[b] UNODC (2010).
[c] SAMHSA (2002, 2003, 2004, 2005, 2006, 2007b, 2008, 2009).
[d] Johnston et al., Annual.
[e] There were important changes to the survey in 2002 that make it difficult to compare with earlier years.

of marijuana per year.[7] That is enough for every past-month user to be continuously intoxicated for every waking hour of the year, assuming the effects of a 0.5 g joint last for 2–3 h.

3.3. *Marijuana consumption in the United States*

The size of a drug market can be measured either by the total quantity users consume or the total amount they spend. Converting the former to the latter is more complex than multiplying grams consumed by the retail price for a gram because one has to account for quantity discounts (Caulkins, 1994), sharing, and – in the case of marijuana – home production. Fortunately, NSDUH added a module in 2002 about marijuana acquisition that helps overcome many of these challenges.

Table 3 displays five estimates of annual marijuana consumption in the United States. Other than Gettman's (1997) estimate of 9830 metric tons (MT), they range from roughly 1000 MT to 5000 MT. Although the estimates vary in their details, they all multiply the numbers of users estimated from general population surveys by assumed rates of consumption per user, often broken down by user type.

All these figures are rooted in general population surveys, and there is perennial concern that surveys underestimate marginalized behaviors for three reasons: (1) use may be concentrated in populations that are outside the surveys' sampling frame; (2) nonresponse may be high, even for users in the sampling frame; and (3) users who are surveyed may underreport their use in their answers. Our sense is that the third is the primary concern for marijuana, whereas all three may be issues for a drug such as heroin. We discuss these issues in turn below.

The sampling frame for NSDUH still excludes some populations (e.g., homeless individuals not in shelters, active-duty military personnel), but it now includes some institutionalized populations (e.g., homeless in shelters and college students in dorms). Given how common marijuana use is, it is unlikely that there are enough people in the excluded populations to create large errors.

Of potentially greater concern is under-sampling important subpopulations that are within the survey's sampling frame (e.g., because they lead marginalized or chaotic lives which makes them hard to locate and survey). One indirect way to get a sense of how severe this issue could be is to use the household survey to estimate the frequency of a behavior that is similarly concentrated among hard-to-survey groups but for which the actual value is known. For example, one might guess that individuals on probation or parole could be hard to survey. However, if we use the NSDUH to estimate how many people in the United States were on probation or parole at any time within the last 12 months, the results (6.1 million and 1.9 million, respectively) are on a par with counts provided by the Bureau of Justice Statistics (6.6 and 1.4 million, respectively). Those errors – of about 0.5 million – are in no way bounds on the errors for marijuana; perhaps it is harder to find marijuana users than it is to find probationers and parolees. But if the error in locating marijuana users were only 0.5 million, that would end up being a quite modest error in percentage terms.

The third issue is survey respondents underreporting their use. The relative lack of social approbation about marijuana use may make this less of a problem than it is for drugs like cocaine and heroin, but it is still an issue. Kilmer and Pacula (2009) partially based their 20 percent underreporting estimate on Fendrich et al.'s (2004) study of a household population in Chicago, which found that 78% of marijuana users self-reported their use. This is also consistent with the share of arrestees who self-reported their marijuana use in the 2008 Arrestee Drug Abuse Monitoring (ADAM) survey (82%; ONDCP, 2009). Additionally, Hser et al. (1999) looked at the validity of self-reported marijuana use for three populations in Los Angeles (those visiting a sexually transmitted disease clinic, emergency room patients, and jail inmates) and found that of those testing positive for marijuana, 12.2%, 18.9%, and 23%, respectively, denied using marijuana in the previous 30 days.

One reason Gettman's (2007) estimate in Table 3 is so high is its assumption of 40% underreporting. This figure is based on Harrison et al.'s (2007) finding that, among 12– 25-year-olds in a methodological sub-study of the 2000 and 2001 household surveys, 39.1% of those testing positive for marijuana denied using marijuana in the previous month. Then again, Harrison et al. (2007) note that the detection window for non-heavy use is only 2–7 days versus as much as 30 days for heavy users, so people who used in the past-month but used infrequently can report use but test negative. Indeed, more people self-reported past 30-day use than tested positive (12.7% versus 11.3%). So if one believes

[7] [90% × (21,500 MT − 1658 − 1253 per year) × 88%/(1 − 33%)]/[(15.2 million)/(1 − 20%)] = 1.2 kg/year.

Table 3
Consumption-Based Estimates of the Size of the U.S. Marijuana Market.

Source	Year	User estimate from the household survey (millions)	Approach for calculating amount consumed	Amount (MT per year)	Nominal value ($B)
Abt Associates (2001)	2000	PM users in 2000 (12.1)	Joints per month, grams per joint	1047	$10.5
Kilmer and Pacula (2009)	2005	Separate estimates for two types of users: PM (14.6) and PY ~ PM (10.8). Best estimate assumed 20% underreporting.	Days per user, joints per day, grams per joint	2950 (1300–6150)	$17.1 ($7.6–$35.5)
DEA (DASC, 2002)	2000	11.7 users [a]	Assumed 365 × 1 g for each user	4270	
UNODC (2009) [b]	2008	PY users in 2008 ages 15–64 (24.5)	Low and high estimates of annual consumption: 60 g and 200 g	1472–4907	
Gettman (2007)	2005	PY in 2005 (25). Assumed 40% underreporting.	Calculated with information about days per user (by gender), joints per day, grams per joint	9830	$113

Notes: PM: past month; PY: past year; PY ~ PM = past year but not in the past month; g: gram.
[a] We are unsure how this was generated, but it was listed as "Modified Consumption Estimate" of Abt Associates (2001).
[b] UNODC provided a range for North America (1876–6252 MT), and this figure for the U.S. was adjusted based on data from the 2008 NSDUH.

regular users would generally test positive, then using past-month prevalence might *overestimate*, not underestimate the number of regular users.

There are two other concerns with using this 40% underreporting figure. First, the survey underwent changes in 2002 that include improvements in quality control procedures and a cash incentive for participation. Second, these validity tests focused on adolescents and young adults, not the full household population.

So far, we have discussed only the number of users, which is, in fact, the traditional focus of papers that worry about the limitations of demand-side estimates. However, uncertainties in estimates of amounts consumed per person are just as troublesome. It is very difficult to estimate average grams consumed per year by any of these groups, and it is particularly important to estimate usage for the chronic users who dominate total consumption. Most estimates are based on (1) self-reported days used per year (available from recent surveys), (2) joints consumed per use-day, and (3) estimates of the average joint size. Unfortunately, the question about number of joints consumed was dropped from the household survey in 1994.[8] There are also suggestions that the mix of types of marijuana has changed over the last 15–20 years, with relatively more consumption now of higher-potency sinsemilla (Mehmedic et al., 2010; Burgdorf et al., 2011), which might reduce grams or joints consumed per hour of intoxication and, hence, per day of use.

There is even considerable uncertainty about the amount of marijuana in a joint (Kilmer et al., 2010). That would seem like an easy parameter to pin down, but it is rarely the object of serious scholarly attention. There are also complications stemming from the fact that marijuana is often used communally and not always in the form of a joint (Caulkins and Pacula, 2006).

To better understand the implications of alternative assumptions, we constructed a consumption-based estimate of the size of the U.S. marijuana market based largely on consumption data from the 2009 NSDUH. Table 4 presents a baseline estimate of the total amount of marijuana consumed and shows how this figure changes under alternative assumptions. Exclusively focusing on those included in the NSDUH sampling frame (an assumption made by all studies in Table 3) and assuming 20% of marijuana users denied using yields an estimate of roughly 3800 MT. The supporting calculations are detailed in Panel A of Table 4. (All digits are retained in the calculations to make the arithmetic clear, but at most the first two should be considered to be significant.)

There are a number of alternative assumptions that could be considered, and Panel B highlights a few of them. Since past-month users account for most of the market, we begin by altering the estimates about the number of joints usually consumed during a use day. Replacing the 2.52 with 2 or 3 joints per use-day changes the total amount of consumption in the United States by −19% and 18%, respectively. With seizure evidence suggesting that THC levels have increased over time (Burgdorf et al., 2011), there is reason to believe that the 2.52 figure from 2001/2002 may overstate the current value if users are titrating and maintaining the same level of THC consumption per use-day. There is also uncertainty because there are alternative methods for consuming marijuana besides smoking joints. Whether those who smoke joints consume more or less than those who use pipes, bongs, or vaporizers is an empirical question that is further complicated by the fact that some users consume through multiple methods.

Given that a respondent reports using marijuana, NSDUH inquires about the number of days the person used in the previous year. The baseline figure uses the mean number of days for past month and past year but not in the past month users (156.3 and 29.8 days, respectively). These averages are heavily influenced by extreme values. Since extreme values might reflect false reports and not true extreme behavior, we also consider the total consumption based on median rather than mean reported days of use (120 and 5 days, respectively). This reduces the baseline consumption estimate by more than 26%.

The estimate of 0.43 g of marijuana per joint is based on an analysis of ADAM data (Kilmer et al., 2010), but there are a number of other estimates which range from 0.3 to 0.5 g per joint (Kilmer and Pacula, 2009). The overall results are directly proportional to and, hence, distressingly sensitive to this one value. If the average size of a joint is 0.3 g, then our baseline estimates declines by

[8] This question was included in the 2001–2002 National Epidemiologic Survey on Alcohol and Related Conditions (NESARC) for all past year users, not just those who reported using in the past month. Interestingly, the mean estimate for joints consumed per use-day for past-month users was the same in NESARC as it was for the 1994 NHSDA: ~2.5 joints.

Table 4
Baseline estimate of U.S. marijuana consumption in 2009 and how this value changes under alternative assumptions.

Panel A: Baseline estimate

Row	Variables	Values	Sources
R1	PM: Number of users	16,752,428	NSDUH 2009
R2	PM: Days used in past year	156.32	NSDUH 2009 (mean)
R3	PM: Joints per use-day[a]	2.52	NESARC 2001/2002 (mean)
R4	PY ~ PM: Number of users	11,967,200	NSDUH 2009
R5	PY ~ PM: Days used in past year	29.81	NSDUH 2009 (mean)
R6	PY ~ PM: Joints per use-day[a]	1.17	NESARC 2001/2002 (mean)
R7	Grams per joint	0.43	Kilmer et al., 2010
R8	PM: Total grams	2,837,666,171	=R1 × R2 × R3 × R7
R9	PY ~ PM: Total grams	179,477,017	=R4 × R5 × R6 × R7
R10	% underreporting	20.00%	Various sources
	Baseline – total grams	3,771,428,985	=(R8 + R9) × (1/(1 − R10))

Panel B: Sensitivity analyses

Alternative assumptions	Total grams	% Change from baseline
PM: Joints per use-day = 2	3,039,491,282	−19.4%
PM: Joints per use-day = 3	4,447,063,787	17.9%
Use median estimate for use-days	2,760,569,012	−26.8%
Grams per joint = 0.3	2,631,229,524	−30.2%
Grams per joint = 0.5	4,385,382,540	16.3%
NSDUH misses 25% of all PM users	4,717,317,709	25.1%
Percent underreporting = 40%	5,028,571,980	33.3%

Note: PM = used in past month; PY ~ PM = used in past year, but not in past month. The 2009 NSDUH prevalence and use-day figures were calculated using the ICPSR on-line analysis tool (http://dx.doi.org/10.3886/ICPSR29621.v1).

[a] NESARC inquires about the frequency of use in the previous 12 months. The choices are: 1. Every day; 2. Nearly every day; 3. 3–4 times a week; 4. 1–2 times a week; 5. 2–3 times a month; 6. Once a month; 7. 7–11 times a year; 8. 3–6 times a year; 9. 2 times a year; 10. Once a year. For these calculations we assumed that those in groups 1–6 were past-month users.

more than 30%. If the better estimate is 0.5 g per joint, this would increase the baseline estimate by 16%.

The bottom of Panel B shows that alternative assumptions regarding the omission of regular (past month) users and underreporting can also have a large impact on estimates of the size of the market. If one believes that NSDUH misses 25% of all past-month users (i.e., roughly 5.6 million past-month users are excluded from the sampling frame), the total quantity of marijuana consumed would be slightly more than 4700 MT. And per the earlier discussion about underreporting, assuming the denial rate among marijuana users covered by NSDUH is 40% instead of 20% would increase the baseline estimate by 33% to slightly more than 5000 MT.

In short, uncertainty about any of a number of parameters generates considerable uncertainty about the bottom line. However, some uncertainties matter a lot more than others, and some do not matter much at all. For example, a simple Monte Carlo analysis that simultaneously varies the number of users and use days by user type (i.e., past month user or past year but not past month user) from the 2009 NSDUH within ranges suggested by their 90% confidence intervals shows that such sampling variability within the NSDUH only affects the consumption estimate by about ±5%.[9] That is, the classic source of variability in survey-based estimate is a second-order concern compared to uncertainty about parameters – such as the average weight of a joint – that are largely neglected by the literature.

We can also offer what one might plausibly consider to be a reasonable upper bound. Because marijuana can stay in the system for a number of days after consumption, we would overestimate the number of individuals who use on any given day if we assumed that everyone who tested positive had consumed marijuana within 24 h of taking the test. With previous research finding that a similar number of household survey respondents self-reported past 30-day use as tested positive for marijuana (12.7% versus 11.3%; Harrison et al., 2007), we can multiply past-month prevalence by the average amount consumed per use-day (2.52 joints × 0.43 g per joint = 1.08 g/day) to generate an inflated estimate of the average amount of marijuana consumed each day. Multiplying this figure by 365 days limits annual consumption at 6626 metric tons – a figure that is well below the highest estimate in Table 3's review of the literature.

This is not, strictly speaking, a true upper bound. The important caveat is that, as suggested by the discussion above, positing average consumption of roughly 1 g/day of use is best thought of as an educated guess based on a disappointingly thin literature. There are also potential sampling frame issues, non-representative sampling within the sample frame, and "under-reporting" in the Harrison et al. (2007) study in the form of refusing to take the drug test. Nevertheless, our sense is that those are more than offset by our unrealistic assumption that everyone testing positive had used in the previous 24 h. Thus, if U.S. consumption exceeds 6626 metric tons per year, it is almost certainly because average consumption per day of use exceeds 1 g.

4. What can be done to reduce the uncertainty around consumption-based estimates

The sensitivity analyses above highlight how seemingly minor assumptions (e.g., size of a joint) can have a major impact on consumption estimates and how others can have a minor impact. While there are analytic methods that can incorporate this uncertainty into analysis (e.g., Monte Carlo simulations), more can be done to reduce the uncertainty surrounding these parameters. We offer some suggestions below.

One simple step is adding questions to user surveys about the quantity and type of marijuana consumed and purchased. For market calculations, researchers generally want to know how

[9] Specifically, those four parameters were modeled as independently normally distributed with means equal to their point estimates and standard deviations suggested by their 90% confidence intervals.

many grams of marijuana are consumed during a typical use-day and the number of days of typical consumption in the previous month. Currently, information is collected on the number of days the user consumed in the past month, and use on all of those days is assumed to be typical.

Surveys can directly inquire about grams consumed during a typical use-day; they can also try to generate this value by asking about the typical mode of consumption (e.g., joint, water bong, pipe) and the number of joints or bowls typically consumed during a use-day. Once typical mode of consumption is known, information on the quantity (in grams) consumed can be assessed using methods recently adopted by Dutch researchers which involve showing users four unrolled joints (actual size) and asking which size best represented the size of joints they rolled (Korf et al., 2007).[10] Similar modules could be incorporated into NSDUH, ADAM, and other user surveys.

After asking about typical consumption, surveys could ask how many days in the past month involved typical consumption as well as how many days involved "less than typical" or "more than typical" consumption. Doing so would enable researchers to get a better sense of potential biases caused by only having information on consumption for typical use days and may even help understand the direction of those biases.

It is also important to consider the type of the marijuana being consumed since it may impact how much a user consumes. Obtaining information about the type of marijuana typically consumed and purchased (e.g., low-grade, regular/commercial, or high-grade/sinsemilla) could be incorporated into questions pertaining to days of use. In addition to assisting with our understanding of the size of the market, this information would be very helpful for interpreting self-reported price data also currently being reported.

Finally, we also hope resources will be dedicated to assessing the validity of general population surveys. Considering that the United States spends tens of millions annually on its general population survey, it does not seem inappropriate to dedicate a small amount of that money every few years to assess how much drug use is underreported. As Harrison et al. note, their study "demonstrated that it is possible to collect urine and hair specimens with a high response rate from persons aged 12 to 25 in a household survey environment" (Harrison et al., 2007, p. 4). Collecting this information for a representative sample of general population survey respondents every five years would reduce the uncertainty surrounding estimates of marijuana and other drug markets.

5. Conclusions

Having a sense of scale of illicit drug markets is essential for making projections about consequences of alternative policy regimes. With serious discussions about marijuana policy reform becoming more frequent in the United States and abroad, there is pressing need for objective and non-partisan data about the size of marijuana markets. However, as we note above, there is considerable uncertainty surrounding both supply-side and demand-side estimates of these markets. The inevitable uncertainty surrounding market size estimates puts additional burdens on researchers to incorporate uncertainty into their analysis and communicate this uncertainty to their audiences (e.g., by focusing on ranges instead of point estimates). Whether this uncertainty seeps down to the campaign materials and ballot statements depends on the integrity of the advocate. But without better information, it will continue to be easy to hijack policy discussions with mythical numbers.

We are not optimistic about the ability to improve supply-side estimates as they have intrinsic limitations. The seizure-based approach is almost circular (estimating production as seizures divided by the seizure rate) and production-based estimates for marijuana struggle with the tremendous variability in yield and harvest estimates. Distinct from those concerns, supply-side estimates also rest on documents and datasets that are typically outside the public domain and available only to those with clearances. These figures may seem more certain because they are enshrined in official government publications and are not complicated by uncertainty ranges, but the inability to even state an uncertainty range is a symptom of their weakness, not their certainty.

Beginning with a baseline estimate of U.S. marijuana consumption in 2009 that is close to 3800 MT, we demonstrate how variations in assumptions about some parameters – such as number of use-days, grams consumed per use day, and underreporting – can cause substantial variation in estimates of the size of the market. It is imperative that those who use these figures for analysis and for advocacy be honest about the uncertainty; however, this does not mean that some of them cannot be used for insightful policy analysis. Indeed, for the U.S. marijuana market, we strongly urge using the consumption-based estimates, whose uncertainties can be clearly described, rather than production- or seizure-based estimates. It is also possible, as we discussed above, to reduce the some of the uncertainties surrounding consumption-based estimates and, thus, improve them.

[10] Korf et al. note that respondents were also allowed to report in-between amount (e.g., less than joint A, between joint A and joint B), which increased the number of options to nine. Respondents were heavy users (average days used in previous month = 24.8, S.D. = 8.6), and on average they reported smoking 4.6 joints (S.D. = 3.3) on a typical use-day, with joints including 0.15 g (S.D. = 0.10) of cannabis. As for the potency of marijuana smoked, the authors report: "We had 16 samples analysed that respondents said consisted of light domestic indoor marijuana, we found a THC content of 14.9%. That was significantly less potent than the variant commonly on sale in the Netherlands at the time of the study (19.1%)" (175).

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