Appendix K: Bouchard (2008) Towards a Realistic Method to Estimate Cannibis Production in Industrialized Countries

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Towards a realistic method to estimate cannabis production in industrialized countries

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Among the many difficulties with estimating the size of the cannabis industry is that suitable methodologies for estimating large-scale outdoor illegal drug production in developing countries cannot be used to estimate indoor production in industrialized countries. This article proposes a new approach that overcomes some of these difficulties. The case study is a mature cannabis cultivation industry, located in the province Quebec, Canada. Starting from capture-recapture estimates of the prevalence of growers, the approach combines police and fieldwork data sources on the dynamics of the cultivation industry to correct for typical errors in the assumed productivity rates of different kinds of cultivation sites. Using three different approaches to productivity (ounces-per-plant, yield-per-lamp, yield-per-watt) it was estimated that Quebec cannabis production was approximately 300 tons in 2002; 11% was seized by the police, 33% was consumed within the province, and 56% was potentially exported to the U.S. and to other Canadian provinces.

KEY WORDS: *Cannabis, cannabis cultivation, illegal drug production, capture-recapture, estimation method.*

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Cannabis cultivation is widely dispersed throughout the world—to a point that any distinction between consuming and producing countries is now meaningless. The 2006 *World Drug Report* identified 176 countries where cannabis is produced. In stark contrast, coca leaf production was reported in only six countries (United Nations Office for Drugs and Crime [UNODC], 2006). The ubiquity of cannabis cultivation contrasts with the elusiveness of production estimates. The academic community either prudently refrains from producing any numbers for cannabis production (e.g. Rhodes, Laynes, Johnston, & Huzik, 2001), or legitimately questions the feasibility of such estimation endeavors, especially in the case of cannabis (Reuter, 1996; Reuter & Greenfield, 2001). When estimates are provided, they are labeled as either highly tentative or informed guesses on the size of the industry (U.S. Bureau of International Narcotics and Law Enforcement [BINLE], 2006; UNODC, 2006; Drug Availability Steering Committee [DASC], 2002).

Methodologies that are suitable for estimating large-scale outdoor illegal drug production in developing countries—such as aerial surveys of drug plantations,[1] cannot be used to estimate "production which is carried out in secrecy, in small and dispersed plots, and frequently indoors" (Reuter & Greenfield, 2001, p. 165). The alternative of extrapolating total production from seizure data is also unsatisfactory. First, there is no data for the seizure rate of domestic marijuana production, how it varies from country to country or from one year to the next. One recent example is sufficient to make this point clear. Currently, the best estimate of U.S. domestic marijuana production is 10,000 metric tons, assuming a seizure rate of 17.5% (DASC, 2002). To illustrate the problems with the 10,000 ton estimate, consider that the best estimates of United States consumption are between 1,000 and 2,500 metric tons (Childress, 1994; Rhodes et al., 2001), and that authorities report seizing a similar amount of domestic cannabis each year (UNODC, 2006). The 10,000 ton estimate implies that the United States produces four to ten times more cannabis than it needs to cover domestic consumption—suggesting the U.S. is a very active exporter of cannabis. This is highly implausible given the important quantities of Mexican and Canadian cannabis seized within the U.S. and at its borders (National Drug Intelligence Center [NDIC], 2005; DASC, 2002) and the lack of any reports of seizures of U.S. product in those countries.

As it shall be demonstrated in this article, the problem is not just that we do not know what the seizure rates are, but that there are many reasons to believe that the reported amount of marijuana seized is inflated to begin with. This is not due to any intentional false reporting by the different law enforcement agencies, but rather because of an accumulation of incorrect assumptions in calculating the proportion of marketable product from one cannabis plant. For example, the 2002 DASC report discusses different options to establish a yield per cannabis plant, ranging from a low of 12.5 ounces to a high of 35.7 ounces (oz) or 1 kilogram (DASC, 2002). Growers interviewed for the purpose of the current study would be very happy if these numbers were in the range of possibilities. In reality, even the most experienced growers rarely obtain more than two ounces of marketable cannabis per plant.

A handful of recent studies provides a better knowledge of productivity rates that can be achieved by cannabis growers in industrialized countries (Hough, Worburton, Few et al., 2003; Toonen, Ribot, & Thissen, 2006). The most systematic study in regards to yield per plant has been published in 2006 by plant researcher Marcel Toonen and colleagues. The team analyzed 12 plant samples from each of 77 indoor cultivation sites in different parts of the Netherlands, and which had been seized by the police in the 24 hours preceding the analysis. They found that the median grow room consisted of 259 plants, with a median plant density of 15 plants/m^2, and 510 watts of growth lamps per m^2. In practice, it means that growers put an average of 15 plants under lamps of either 400 or 600 watts. The average yield per plant was 33.7 grams, or 1.2 ounces of flower buds, or 0.99 grams per watt. The study was limited to indoor cultivation sites. Thus, it remains unclear whether outdoor plants generate more or less marketable cannabis.

The current study

Taking advantage of a diverse array of data sources on the cultivation industry in a Canadian province (Quebec), the current article addresses these shortcomings and proposes a new method to estimate the size of cannabis production in Quebec. In many ways, the method is inspired by the approach used to produce the much less controversial drug consumption estimates. First, it starts by estimating the size of the populations involved—here, the prevalence of cannabis growers active in a given year. Even the specific estimation method used in this article (a capture-recapture model) has been widely used to estimate the prevalence of hard drug users (Bohning, Suppawattanabodee, Kusolvisitkul, & Viwaywongkasem, 2004; Calkins & Atkan, 2000; Hser, 1993; Choi & Comiskey, 2003; Hickman, Cox, Havey, Howes, Farrell, Frischer et al., 1998; Smit, Toet, & Van der Heijden, 1997; Brecht & Wickens, 1993). Second, information on cultivation patterns is used to break down the population into categories, depending on growers' productivity rates and the cultivation technique that they use.

For many reasons, the ambitions of the study are modest. I cannot avoid the use of a series of uncertain assumptions and face similar difficulties as previous studies in establishing realistic parameters for aggregated populations of cannabis growers. Nonetheless, each assumption used in this article is backed and validated by empirical research, each is conservative, and the final estimates appear to have face validity.

Data

The combination of numerous data sources is necessary to estimate cannabis production. Police data on cannabis cultivation arrests are needed for the capture-recapture analysis, and data on seizures are used to approximate a distribution of cultivation sites of different sizes and techniques (outdoor, indoor-in soil, and hydroponics) for the industry as a whole. Finally, fieldwork data on the dynamics of individual production sites are required to establish key parameters relative to the productivity and division of labor involved in sites of different sizes, and using different cultivation techniques.

Arrest data on cannabis cultivation

All cannabis cultivation arrests between 2001 and 2003 were retrieved from the MIP (Module d'Informations Policières) data set, which includes all crime-related incidents in Quebec. A single arrest may contain many different criminal charges. All arrests for which the first or second charge (or most serious charges) was for cannabis cultivation were considered cannabis cultivation arrests. The 5,607 cannabis cultivation offenders arrested between 2001 and 2003 had a mean of 1.03 cultivation-related arrests (for a total of 5,757 arrests). Arrest data distinguish between two cultivation techniques: soil-based growing (79.4%) and soil-less or hydroponics growing (21.8%). The total does not round to 100% because 67 offenders (1.2%) were arrested on both cultivation charges. Those offenders were randomly distributed into the two arrest distributions, respecting the relative weight of each cultivation technique in the data. Unless indicated otherwise, indoor will refer to the soil-based technique, and hydroponic to soil-less cultivation.[2] The mean of arrested growers (34 years old) and the proportion of females (15%) is similar to arrest data reported elsewhere (Plecas, Malm, & Kinney, 2005).

Police seizures

A second data set comprising all the seizures made by the Quebec Provincial Police (QPP) for the years 2000 and 2001 (N = 3212) was used to obtain aggregate information on the size of cultivation sites. Seizures were classified in three categories: outdoor (65%), indoor (30%), and hydroponics (5%). Soil-based techniques are over-represented compared to arrest data for two reasons. First, only 14% of outdoor and 76% of indoor seizures lead to an arrest, compared to 95% of hydroponic cases. Second, although the QPP covers 70% of the province, data from Quebec's largest city center (Montreal) are missing from this database but are included in the MIP. There are no reasons to believe that this should have an impact on the variables for which this data set will be used (average size of cultivation sites, and distribution of sizes per technique, see table 1).

Fieldwork data

Information on the co-offending patterns and on the productivity rates of cultivation sites were obtained from a convenience sample of 20 interviewed growers who were active in the Quebec industry between 1993 and 2005. I personally interviewed nine growers between 2004 and 2006. Growers were recruited in a variety of informal ways,[3] and interviews were conducted in cafés and pubs in Montreal and Quebec City. Information was gathered on many topics, including details on the dynamics of their career in cannabis cultivation, and a variety of issues touching the social and economic world of cannabis cultivation. Only information on key variables regarding the co-offending patterns and productivity rates of their sites were analyzed for the purpose of this study.

I also obtained access to the written accounts of 17 interviews conducted by undergraduate students in a criminology class at Université de Montréal between 1998 and 2003. Eleven interviews were added to the sample because they contained precise information on at least two of the key parameters used in this study: the number of plants grown for a specific crop, the number of co-offenders involved from start to finish, and one or various productivity measures described in full later in the article. Nineteen of the 20 growers in the sample were male, on average they were 27 years old, were involved on cultivation sites of 111 plants. The sample described the cultivation patterns of 36 crops (10 outdoor, 15 indoor, and 11 hydroponics). Only crops for which growers reported different parameters (e.g. change in the number of plants, co-offenders involved, productivity rates) were added to the database. Compared to arrest data, the interviewed sample comprised more males and younger growers who were involved, on average, on smaller cultivation sites.

Methods

Estimating the prevalence of cannabis growers

The prevalence of growers is estimated using Zelterman's (1988) truncated Poisson estimator. If data on known arrests and re-arrests follow the Poisson distribution specified by Zelterman's model (mixed), the missing cell in the distribution should be estimated correctly, that is, the number of cannabis growers with zero arrests. For data to follow a general Poisson distribution, a number of assumptions must be respected: 1) the population under study must be closed; 2) the population has to be homogenous; 3) the probability for an individual to be observed and re-observed must be held constant during the observation period. Such assumptions when using data on criminal populations may be violated. However, Zelterman's estimator has been shown to be robust with regard to deviations from assumptions, and successful in estimating hidden populations of drugs users (Choi & Comiskey, 2003; Smit et al., 1997; Bohning et al., 2004), drug dealers (Bouchard & Tremblay, 2005), and cannabis growers (Bouchard, 2007). It is given by:

$$Z = N / (1 - e^{(-2*n2/n1)}) \quad (1)$$

Where Z is the total population, N is the total number of individuals arrested with a cannabis cultivation charge, n1 is the number of individuals arrested once, and n2 is the number of individuals arrested twice in a given time period.

Zelterman's model provided an excellent fit to the data (see Bouchard, 2007 for details), mainly because very few growers were arrested more than twice. Bouchard (2007) provides the arrest distribution and more specific procedure used to estimate the prevalence of outdoor, indoor, and hydroponic growers for 2002 presented in table 1. Bouchard noted that hydroponic growers represented 22% of growers arrested but 27% of the total population of growers, indicating a lower risk of being arrested compared to soil-based growers.

TABLE 1
Annual prevalence and risks of detection by type of cultivation sites, Quebec, 2002 (from Bouchard, 2007)

Type of cultivation site	*Prevalence of growers*[a]	*Median size (# of plants)*	*Co-off/med size*[b]	*Percent of Cases*	*Prevalence of cultivation sites*[c]	*Mean annual # of cases*	*Risk of detection*
OUTDOOR							
Small	14,644	9	2.9	36.8%	1,858	358	19.3%
Medium	14,644	45	3.3	36.5%	1,620	355	21.9%
Large	14,644	228.5	5.5	26.6%	708	259	36.6%
INDOOR							
Small	25,089	7	3.0	19.8%	1,656	75.5	4.6%
Medium	25,089	51	3.4	26.1%	1,926	99.5 —	5.2%
Large	25,089	360.5	5.9	54.1%	2,301	206	9.0%
HYDROPONIC							
Small	14,978	18	3.1	1.9%	92	1.5	1.6%
Medium	14,978	59	3.4	17.2%	758	13.5	1.8%
Large	14,978	485	5.8	80.9%	2,089	63.5	3.0%
TOTAL					13,008	1431.5[d]	11.0%

[a] Adjusted prevalence figures for outdoor and indoor growers for 2002.
[b] As estimated through OLS regression, using fieldwork data. See table 2.
[c] As estimated by Eq. (2) below.
[d] The mean number of seizures for 2000-2001 is 1,606. However, the number of plants was not specified in 10.8% of cases (or 174.5 per year). Adding these cases increase the risks of detection by 1.3%, or from 11.0% to 12.3%.

The estimates are based on arrest data. Thus, the correct definition is that the capture-recapture model estimates the population of growers "at risk of being arrested." Not all growers are at risk of being arrested. For example, seizure data indicate that only 14% of police interventions on outdoor sites lead to an arrest, in which case a capture-recapture analysis might underestimate the population of growers. The population estimates presented in table 1 were adjusted to reflect this possibility, but the fairly high seizure risks (19-37%) calculated for outdoor sites (table 1, last column) indicate that the prevalence estimates remain conservative. Nonetheless, the estimates appear reasonable enough to derive lower risks of seizure for the less vulnerable indoor (5-9%) and hydroponic sites (2-3%). The overall validity of the estimates has been established in a previous paper, using the same data (see Bouchard, 2007).

Median size and % of seizures

Not all growers work on sites of similar size, or share the same commercial motivations (Weisheit, 1992; Hough et al., 2003). It was necessary for the current analyses to distinguish between three categories: personal use (1 to 20 plants), small commercial sites (21 to 100 plants), and large commercial sites (101 + plants). Reasons for this include the relatively important proportion of marijuana cultivation sites with more than 100 plants, and also because the division of labor involved in small scale and large scale operations differs according to the type of technique used as well as the size of operations. Table 1, column 3 shows that hydroponics sites are systematically larger than sites using other techniques and that very few seizures of such sites involve less than 100 plants (19%), compared to indoor (46%) and outdoor (73%) techniques.

If police seizures overestimate the proportion of larger cultivation sites, the effect on the estimates are not obvious: increasing the median size of operations will underestimate the prevalence of active cultivation sites. However, when the time comes to estimate cannabis production, inflated average size figures will overestimate the total quantities involved per site.

Number of co-offenders for an average site

Interviewed growers were asked to report the total number of persons involved in the cultivation process: installing the equipment, daily maintenance, harvesting, and manicuring. As expected, the collected data indicates that the number of co-offenders is a function of the number of plants grown: the more plants, the more co-offenders ($r = .88$, $p < .001$). However, the function is not similar for all techniques. Regressing the number of co-offenders involved per site on the number of plants grown, I found the parameters presented in table 2.[4] Although caution is advised in giving too much weight to parameters derived from such small samples, the results warrant two observations. First, even for smaller sites, cannabis cultivation requires a minimum of three co-offenders from start to finish. Second, hydroponic sites benefit from greater economies of scale at larger sizes, compared to other techniques (indicated by the smaller b value). Such a result is consistent with interview data. Growers report that an important difference between hydroponic and indoor soil-based growing is that, once installed, the former functions almost entirely on an automated system that requires little assistance.[5] In contrast, soil-based growing requires considerable daily labor to irrigate the plants, but perhaps more importantly, to change soils after each harvest—a particularly cumbersome activity at larger sizes.

TABLE 2 **Regressing the number of co-offenders involved per cultivation site on the number of plants grown**

Cultivation technique	*a (constant)*	*b*	R^2	*p*
Outdoor (N = 10)	2.805	0.0116	.51	.02
Indoor (N = 15)	2.962	0.0082	.28	.04
Hydroponics (N = 11)	2.981	0.0057	.86	.00

Deriving an estimator for the prevalence of grow sites

The prevalence of grow sites can be derived from these parameters. From Eq 1. I derived an estimator of the number of cultivation sites:

$$S = \sum (Z_i/c_i)\lambda_{i,n} \quad (2)$$

S is the annual number of cultivation sites at risk of detection. Z is the prevalence of growers of type i, c is the number of co-offenders working on a median size plot of type i, and l represents the proportion of seizures for type i and of sizes n.

For example, to estimate the number of indoor sites of more than 100 plants, I divide 25,089 by 5.9 co-offenders for a median size of 360.5 plants, and then multiply by 0.54, the seizure rate for outdoor sites of more than 100 plants. I obtain a prevalence of 2,301 of such cultivation sites for the year 2002, subjected to an estimated risk of seizure of 9%. For the industry as a whole, Eq. 2 estimates that 13,008 cultivation sites were active in 2002, and that 11% of them were detected by the police.

Results

Productivity measures and key assumptions

Table 3 summarizes the findings from the fieldwork data with regards to different productivity measures of cultivation sites. All calculations presented in table 3 were constructed from asking growers more straightforward questions, such as: "*How many plants did you harvest for that particular crop? How many total lamps were running at the same time? What type of lamps were they, in number of watts?*

Plant yield has been the most widely used parameter in the literature, either to derive a quantity of marketable cannabis from a number of plants seized by the police, or from an aerial survey of cannabis cultivation sites. Table 3 suggests that outdoor cannabis plants yield more ounces per plant (1.9 ounces) than cultivation sites located in indoor settings (mean = 1.2 oz). Indoor and hydroponic growers have a tendency to grow smaller plants and buds, mainly because the vegetative and flowering periods are shorter, and plant density is higher compared to outdoor sites. In addition, most of these commercial growers are content with only harvesting the flower bud growing at the top of the plant. In contrast, outdoor plants sometimes have enough light, and for a long enough period of time, to develop buds at the bottom. The plant yields presented in table 3 are much lower than those used by the police and government agencies (12.5 to 37.5 oz in DASC, 2002), which explains why production figures extrapolated from seizure data appear to be so high.[6] However, the plant yields reported by growers are directly in line with those reported in other empirical research (Hough et al., 2003; Toonen et al., 2006).

TABLE 3 **Different productivity measures of cannabis cultivation sites according to the technique used by growers**

Type of cultivation site	*oz/plant*	*oz/lamp*	*Plants/ lamp*	*Grams /watt*	*Median watts/ plant*	*Crops/ year*
OUTDOOR (N = 10)	1.9	–	–	–	–	1.0
INDOOR (N = 15)	1.3	10.0	10.3	0.4	62.5	2.6
HYDROPONICS (N = 11)	1.1	19.7*	23.0	0.7*	38.9	3.6
Total indoor/ hydro	1.2	13.8	15.3	0.5	49.6	3.0
TOTAL ALL	1.4	13.8	15.3	0.5	49.6	2.3

* $p<.05$

Most indoor growers prefer to discuss yield per lamp, rather than yield per plant, perhaps because it is easier. A rule of thumb used by growers is that one 600 or 1000 watt metal halide/HPS[7] lamp will produce one pound of cannabis, regardless of the number of plants placed under the lamp. The choice, then, is to play the volume or the growth strategy: growing numerous but smaller plants (the volume strategy); or growing less numerous but bigger plants (the growth strategy). One hydroponic grower who supervised the largest production site in the sample noted that he preferred more plants (e.g. 40) over fewer plants (e.g. 15) under each lamp, because this meant that a bad crop (losing 20-30% of the plants) would not place undue pressure on the productivity of the remaining plants. Column 4 (plants/lamp) and column 3 (oz/lamp) illustrate the soundness of this rationale. Indoor growers obtained lower productivity rates (10 oz/lamp) than hydroponic growers (19.7 oz/lamp) in part by putting fewer plants, on average, under each lamp (10 vs. 23 plants). On the flip side, indoor growers had a better yield per plant (1.3 oz) than hydroponic growers (1.1 oz), although the difference was not statistically significant. Furthermore, because the number of plants grown per site is a central criterion used by criminal courts to assess the seriousness of cannabis cultivation offences (Plecas et al., 2005), the volume strategy will turn against those growers in the event of a police raid.[8]

Some growers prefer to assess productivity in specific wattage, rather than mere number of lights. In fact, the grams-per-watt ratio (0.5 gr./watt, column 5) is perhaps the best parameter to assess the productivity for indoor growing techniques. It takes both the lamps and their intensity into account.

The final important productivity parameter presented in table 3 is more straightforward: how many crops can be harvested each year? As expected, the answer was only one for outdoor growers in Quebec. Indoor and hydroponic growers reported producing a mean of three crops per year for one cultivation site. This crop frequency is the modal answer for most small-time commercial growers, such as the ones interviewed for this study.[9] Crop frequency, however, increases with size: the mean number of crops per year was significantly higher for sites of more than 100 plants compared to others (4.4 vs. 2.5 crops per year, $p < .05$). Large commercial growers sometimes install two, or even three grow rooms at one site, giving them enough flexibility to harvest up to eight crops per year. However, most do not harvest this many crops, simply because they stop during the summer, when the temperature and humidity reach such high levels that the cannabis plants can easily be damaged.[10] This is supported by seizure data; indoor and hydroponic seizures reach annual lows between in July and August (less than 5% of seizures each month).

A final parameter, plant attrition, is important in estimating cannabis production; not all seeds or cuttings placed in the ground will reach maturity. One reason is that cannabis plants can be either male or female; only female plants produce the buds that cannabis users will smoke. Male plants, therefore, need to be removed as soon as sex can be identified, which happens between four to eight weeks after the plants are placed in soil, depending on the specific genetics used. Approximately 50% of males and females will be grown from any bag of seeds.[11] This led Wilkins and colleagues, (2002), for example, to double his estimates of the number of plants potentially grown in New Zealand.

Our fieldwork data indicates that fewer than 50% of all plants grown (or of all plants seized by the police) are males—at least for the Quebec industry. First, most growers use cloning techniques, or buy clones from a producer. Cloning consists in taking cuttings from a female mother plant in order to make an exact reproduction. Close to 70% of all crops described by interviewed growers were started from female clones.[12] Even when growers start from female plants, not all of them reach maturity. Some plants do not receive enough light (or sun) or water for efficient growth, some are eaten by small animals, and others are infested by bugs or fungus. Even the most experienced growers acknowledged losing plants in almost each crop. When growers estimated plant attrition, they reported that between 60% and 95% of female plants would reach maturity. Weisheit (1992) used a 65% figure in his important study on outdoor growers in the U.S. Lacking precise data on this issue, I use conservative figures: a 35% loss for outdoor growers, and a 25% loss for indoor and hydroponic growers. A 15% figure will be used for the light/watt approaches because losses are already partly taken into account in the productivity measures. In other words, every plant counts in the yield per plant approach, but this is not the case with the other approaches. Sensitivity analyses show that the effect of modifying this particular assumption on the production estimates is small: reducing the attrition rate by 5% also reduces production estimates by approximately 5%.

Estimating the size of cannabis production

Tables 1 to 3 permit three different cannabis production estimates. All estimates use the same four baseline parameters: a) the prevalence of production sites of given size and cultivation technique; b) the mean number of plants (from seizures data); c) an attrition factor; and d) the mean number of crops per year. Then, each of the three estimates uses a different yield parameter to transform plants into quantities: 1) the mean yield per plant (in ounces); 2) the mean quantity produced per lamp (in ounces); and 3) the mean quantity of cannabis produced per watt (in grams).[13]

Results of the yield-per-plant estimate are presented in table 4. The yield per plant for a type of cultivation site has been calculated by regressing plant yield (in ounces) on the number of plants grown in fieldwork data, and applying the formula to the adjusted mean size for the industry as a whole.14 The reason is that fieldwork data showed that plant yield decreases as a function of size. For example, the yield-per-plant estimate for large hydroponic sites is 0.9 ounces, whereas for smaller sites the yield-per-plant estimate is 1.3 ounces (table 4). In line with the productivity rates derived from the interviews with growers, large indoor and hydroponic commercial sites were attributed a four crop-per-year ratio. The adjusted mean size simply reflects the mean number of plants seized by the police minus plant attrition. The final calculation is simple:

(3) Total cannabis production (in oz) =
Prevalence*(Adj. mean size*oz/plant*crops/year)

The total yield-per-plant estimate of cannabis production in Quebec in 2002 is 302 metric tons. The last column of table 4 shows that the minority of very large indoor and hydroponic cultivation sites account for the bulk of cannabis production in the province. According to these estimates, 34% of all active sites account for 93% of cannabis produced in Quebec is carried out by in the province. In contrast, outdoor production accounts for 32% of all sites only for a little more than

TABLE 4

The yield-per-plant approach to estimate cannabis production in Quebec, 2002

Type of cultivation site	*Prevalence of cultivation sites*	*Attrition rate*	*Adjusted mean size (plants)*	*oz/plant*	*Crops/year*	*Total production (metric tons)*	*% of total*
OUTDOOR							
Small	1,858	0.35	5.9	2.1	1	0.6	0.2
Medium	1,620	0.35	31.9	2.0	1	2.8	0.9
Large	708	0.35	260.0	0.7	1	3.8	1.3
INDOOR							
Small	1,656	0.25	6.0	1.3	3	1.1	0.4
Medium	1,926	0.25	41.3	1.3	3	8.6	2.8
Large	2,301	0.25	493.5	1.0	4	129.3	42.8
HYDROPONIC							
Small	92	0.25	12.8	1.3	3	0.1	0.0
Medium	758	0.25	47.3	1.3	3	3.8	1.3
Large	2,089	0.25	747.0	0.9	4	151.7	50.2
TOTAL	13,008					301.8	100.0

2.4% of total production. These results mirror well-known findings on drug use: a small minority of heavy users accounts for the majority of illegal drug consumption (e.g. Rydell & Everingham, 1994).

How does this 302-ton estimate compare to quantities derived from other productivity measures? All yield extremely similar estimates. The yield-per-lamp approach estimates cannabis production at 301 metric ton (tTable 5), while the yield-per-watt approach produces a 307 metric ton estimate (table 6). The details of the calculations are not presented due to space limitations (those interested should contact the author). While not a major surprise given the fact that all methods share four assumptions, the similarity is interesting, because each approach rely on two independent assumptions.

Taken together, the three approaches give a range of cannabis production in Quebec of 301 to 307 metric tons annually. If one approach is preferable to the other, the yield-per-watt approach would have my vote, because it takes into account not just the number of lamps but also their intensity. However, sensitivity analyses (not shown) conducted on all three approaches showed that the yield-per-watt approach was slightly more sensitive to changes in the various assumptions. The skewed distributions for wattage parameters found in the sample of interviewed growers and the increased importance that this approach places on large cultivation sites explain the volatility of the wattage estimates. But given the small difference between all three estimates, no single approach has to be chosen over the others for now. For simplicity, and because of the uncertainty regarding the estimates, a 300 metric ton figure will be used for the remainder of the article.

Comparing with alternative estimates

The 300 metric ton estimate can be used to assess the plausibility of current estimates provided by the UNODC. According to the 2006 *World Drug Report*, Canada's annual cannabis production is estimated at between 960 and 2400 metric tons. These numbers suggest that Quebec produces between 31%

TABLE 5
The yield-per-lamp approach to estimate cannabis production in Quebec, 2002

Type of cultivation site	*Prevalence of cultivation sites*	*Attrition rate*	*Adjusted mean size (plants)*	*Crops/year*	*Lamps/ sites*	*oz/lamp*	*Total production (metric tons)*	*% of total*
OUTDOOR								
Small	1,858	0.35	5.9	1	–	–	0.6	0.2
Medium	1,620	0.35	31.9	1			2.8	0.9
Large	708	0.35	260.0	1	–	–	3.8	1.3
INDOOR								
Small	1,656	0.15	6.8	3	0.5	12.8	0.9	0.3
Medium	1,926	0.15	46.8	3	3.3	13.1	6.9	2.3
Large	2,301	0.15	559.3	4	27.8	16.9	121.3	40.3
HYDROPONIC								
Small	92	0.15	14.5	3	1.0	12.9	0.1	0.0
Medium	758	0.15	53.6	3	3.7	13.2	3.1	1.0
Large	2,089	0.15	846.6	4	36.3	19.0	161.7	53.7
TOTAL	**13,008**						**301.3**	**100.0**

TABLE 6

The yield-per-watt approach to estimate cannabis production in Quebec, 2002

Type of cultivation site	*Prevalence of cultivation sites*	*Attrition rate*	*Adjusted mean size (plants)*	*Crops/year*	*Wattage/ site*	*Yield watt (in grams)*	*Total production (metric tons)*	*% of total*
OUTDOOR								
Small	1,858	0.35	5.9	1	–	–	0.6	0.2
Medium	1,620	0.35	31.9	1	–	–	2.8	0.9
Large	708	0.35	260.0	1	–	–	3.8	1.2
INDOOR								
Small	1,656	0.15	6.8	3	907.1	0.40	1.8	0.6
Medium	1,926	0.15	46.8	3	1,851.3	0.66	7.0	2.3
Large	2,301	0.15	559.3	4	19,128.1	0.69	120.9	39.4
HYDROPONIC								
Small	92	0.15	14.5	3	1,927.6	0.40	0.2	0.1
Medium	758	0.15	53.6	3	2,120.6	0.66	3.2	1.0
Large	2089	0.15	846.6	4	28,953.7	0.69	166.2	54.2
TOTAL	**13,008**						**306.6**	**100.0**

and 12.5% of Canadian production. The 960 ton estimate is more plausible (31%), but seizure data indicate that it may be too high. Between 2001 and 2003, 42% of all cannabis seized in Canada was grown in Quebec. Extrapolating from the 42% and 300 ton figures would yield an estimate of 714 metric tons of cannabis produced in Canada in 2002.

If the 300 ton figure is accepted, then the actual seizure rate would be 10.3% in Quebec for 2002. Interestingly, the seizure rate for plants compares to the risks of seizure calculated for cultivation sites in Quebec found in table 1 (11.0%). The seizure rate is slightly lower due to the fact that the larger hydroponic cultivation sites carry the majority of production, but have very low risks of seizure compared to other parallel enterprises (table 1). Note that the risk of arrest for growers was about four times lower (2-5%) than the figures estimated for cultivation sites (Bouchard, 2007).

Comparing with consumption estimates

It is useful to compare these results to consumption figures. Estimating cannabis consumption in Quebec or Canada is not straightforward. First, the general household surveys do not ask precise questions on quantities. The prevalence of different types of users can be identified, but the quantity of cannabis used per joint, the number of consumption episodes, or the quantity of joints per episode are mostly absent from the main surveys (the drug use survey among Ontario students is the exception; Adlaf & Pagalia-Boak, 2005). Second, Canada does not collect systematic data on drug use by arrested offenders.

Fortunately, data and analyses from other comparable countries are available and can be used to compensate for the missing Canadian data. Pudney and colleagues (2006) estimate of illegal drug consumption in the United Kingdom (U.K.) was particularly well-done, and it inspired the less detailed approach taken here (note that I only had access to the results of the consumption surveys, as opposed to the raw data in Pudney et al.'s study). The approach is as follows. First, the total number of past year users was estimated by age group from two surveys: a) Canada's 2004 general household survey on drug use for 15+ years old respondents (Adlaf, Begin, et al., 2005), and b) Quebec's 2004 general drug use survey among high school students for the 12-14 age group (grade 7 and grade 8 students in Dubé and colleagues, 2006). A past year prevalence of 946,140 12+ cannabis users was derived from these sources (table 7, column 2). Second, the Canadian survey was used to divide this figure into categories of users: experimental users (one or two consumption episodes per year), occasional (once or twice every three months), monthly, weekly, and daily users. Each has been attributed a number of days of cannabis use per year according to the definition (table 7, column 4). Intervals could also be used to produce a low and a high estimate, but for simplicity, I used the figures suggested in the survey. Each type of users does not use similar quantities per day of use. Following Pudney et al.'s (2006) strategy, two quantities per day of use were attributed (table 5): 0.5 grams (a little more than one joint) per day of use for non intensive users (experimental, occasional, and monthly users), and 1.2 grams per day for more intensive users (weekly and daily users). Table 7 presents estimates for the year 2003, the year preceding the 2004 survey.

According to the figures presented in table 7, 88.7 metric tons of cannabis was consumed in Quebec in 2003. Such an estimate means that each past year user would have used 94 grams of cannabis in 2003 similar to many other estimates for other developed countries showing analogous prevalence levels. For example, Childress (1994) pointed out that attributing a proportion of 100 grams per past year user accounted for the differences between light and heavy users, and approximates quite well total cannabis consumption in the U.S. The 100 grams-per-user benchmark was also found in Pudney et al.'s (2006) thorough study. They estimated cannabis consumption at 416 metric tons for 2003-2004 in the U.K. a quantity spread over about four million past year cannabis users.

TABLE 7

Estimating the quantity of cannabis consumption in Quebec, 2003

Type of users	*Number of users*	*% of users*	*Number of days of use/year*	*Quantity/ days of use (grams)*	*Grams/ year/ user*	*Total production (metric tons)*	*% of total*
Yearly	196,601	20.8	1.5	0.5	0.8	0.1	0.2
Occasional	235,354	24.9	6	0.5	3.0	0.7	0.8
Monthly	151,231	16.0	12	0.5	6.0	0.9	1.0
Weekly	191,875	20.3	52	1.2	62.4	12.0	13.5
Daily	171,080	18.1	365	1.2	438.0	74.9	84.5
	946,140	**100.0**				**88.7**	**100.0**

The estimates presented in table 7 do not take into account cannabis use by arrestees, or by populations that are not reachable through general household phone surveys. If Quebec arrestees' market share is assumed to be similar to the one calculated by Pudney *et al.* (2006) for the U.K., about 18 metric tons should be added to Quebec's 89 ton estimate (or a 17% market share for arrestees), for a total of 107 metric tons. Thus, lacking more precise data, it is estimated that between 89 and 107 metric tons of cannabis was consumed in 2003 in Quebec. For simplicity, a 100-ton figure will be used for the remainder of the article.

If one accepts the consumption (100 metric tons) and production estimates (300 metric tons) for 2002/2003, only 33% of the cannabis produced in Quebec is consumed within the province. Of the remaining 200 metric tons, 31 have been seized by the police. This means that up to 56% of total production, or 169 metric tons of cannabis was available for exports to the U.S., or to other Canadian provinces. The fact Quebec exports cannabis to the U.S. is known. U.S. authorities reported seizing 30 metric tons of cannabis from Quebec and British Columbia in 2005 (NDIC, 2006). Second, all the growers I personally interviewed for the purpose of this study knew cannabis exportation stories in Quebec—three reported that some of the cannabis they grew was exported to the U.S., and one respondent reported having smuggled cannabis himself to the U.S. on a few occasions.

Is the 169 metric ton export figure plausible? A first approach is to look at seizure figures for Canadian cannabis in the U.S. The Royal Canadian Mounted Police (RCMP) (2005) recently reported that 15.7 metric tons of cannabis originating from Canada has been seized in the U.S. in 2003. Applying the domestic seizure rate to that figure implies 6.6 metric tons of cannabis (or 42%) seized in the U.S. in 2003 was smuggled from Quebec. It can also be assumed that much larger quantities are smuggled but are not seized by U.S. authorities. If all 169 metric tons are exported to the U.S., then it would mean that exported cannabis from Quebec is subject to a 4 % seizure rate. This calculation is offered as a quick way to illustrate the meaning of these numbers, but it relies on many uncertain and unverified assumptions, including the possibility that a sizable quantity of cannabis is exported to other Canadian provinces.

A second approach is to examine if the organization of the Quebec cannabis cultivation industry is suitable to export such large quantities to the U.S. One can assume that most-to-all exported cannabis comes from large commercial sites. Moreover, smugglers are unlikely to export quantities under 50 to 100 pounds at one time, and groups who specialize in exporting are likely to gather such quantities from the smallest number of cultivation sites possible. One 850 hydroponic plant cultivation site can produce about 50 pounds per crop. Such sites are the most suitable to subsequent distribution to the U.S. Tables 4 to 6 showed that large hydroponic cultivation sites produced 152 to 166 metric tons of cannabis annually. A reasonable assumption is that such quantities are produced by the organizations that have access to the criminal networks necessary to smuggle large quantities into the U.S., and that most of it is indeed exported to the U.S.

Conclusion

Many scholars have criticized illegal drug production estimates published in the past, with legitimate claims on the use and misuse of the available data and concepts (National Research Council, 2001; Reuter, 1996; Thoumi, 2005). Their conclusions were pessimistic; some argued that precise estimates were unimportant to the policy makers who command them. However, implicit in their critique is that estimates are not important until they are well-done. Even though it leaves many questions unanswered, the current article is a contribution towards that goal.

First, the article confirms that the yield per cannabis plant has been much exaggerated in past research on the size of the cannabis production industry, helping us understand why production estimates often appear to be too high. Growers interviewed for the purpose of this study reported harvesting between one and two ounces of saleable cannabis per plant grown, and it was shown that location matters: outdoor plants yield larger quantities than most plants commercially grown indoors. Second, the article introduces two other productivity measures that describe well the dynamics of indoor cannabis cultivation: the yield per watt and the yield per lamp used in the greenhouse. All three measures yield production estimates that remain very close to each other, but the wattage/lamp approaches appear to better capture the enhanced productivity of large commercial sites. In addition, these productivity measures can be used to correct past and future estimates of the quantity of cannabis seized by the police. Finally, the article by-passes one of the major difficulties of estimating the size of indoor cannabis cultivation in developed countries by first estimating the prevalence of growers from arrest data. Doing so adds an important assumption to the general approach, namely that capture-recapture analysis can approximate well the size of the populations of growers involved. The results derived from the capture-recapture pass the available validity tests, but more research on different populations and with different models is needed to establish more precisely the degree of confidence one can have in these models (also see Bouchard, 2007).

Despite the aforementioned empirical contributions, should the actual numbers produced in this study matter to policy makers? They should. The fact that Quebec exports more cannabis than is consumed by local users should significantly lower expectations of what can be accomplished in terms of reducing cannabis consumption in Quebec through eradication programs. What the story presented in this article tells us is that despite the substantial law enforcement efforts devoted to eradication, the police only manages to seize 10% of the cannabis produced in the province, a good 140 metric tons away from affecting supply for users in Quebec. A related chapter of this story is that the larger and more productive hydroponic sites have lower risks of detection than the smaller and less sophisticated enterprises—preserving hydroponic growers' incentives to increase organizational size. Hence, the numbers imply that the current policy appears inequitable in its application, and should be revised accordingly.

The substantive conclusions of the article leave many uncertainties regarding such estimation exercises. There is no way of knowing whether the estimates are close, far, or right on the mark. The approach relies on many assumptions. Future research should try to replicate, and improve the approach presented here. All that can be said for now is that the 300 ton estimate found in this study possesses some attractive qualities: it is based on parameters derived from empirical research, it is more conservative than estimates provided by the authorities, it yields a reasonable seizure rate given the level of law enforcement on the industry, and it confirms Quebec as an exporting province.

Notes

1. The only survey for cannabis is carried in Morocco and it is particularly well-done (UNODC, 2007). Satellite pictures are taken of all major cultivation provinces to estimate yield per hectare. Then, a sample of these sites and estimates are cross-checked on the ground by a group of researchers to assess their validity.
2. Soil-based cultivation can be carried out either in outdoor or indoor settings, a distinction that is only made in seizure data. Hydroponic growing is always carried out indoors.
3. One respondent was referred by a colleague criminologist who was supervising him while he served the end of a federal sentence in a halfway house in Montreal after being found guilty of cannabis cultivation. Two other respondents were referred by a criminology student after a seminar I taught on cannabis cultivation. The six others were referred to me by mutual acquaintances after learning about the research. All interviews were tape-recorded, and respondents were asked to speak about their past—never current, if any—experiences in cannabis cultivation.
4. I used a simple linear regression model of the form $C = a + b*p$, where C is the number of co-offenders per site and p is the number of plants grown per site.

5. But problems may occur and, in practice, growers will still visit hydroponic sites everyday.

6. Part of the discrepancy can be explained by the way that police weigh the plants: sometimes they leave use the leaves, stems, seeds, and trunk, in addition to the buds. Only cannabis buds are marketable and sold in Quebec. Any estimation using the weight of cannabis plants, whether before or after they are dried, is meaningless in most industrial countries.

7. Most experienced growers will switch from a metal halide to a HPS bulb when plants enter the flowering phase.

8. As it happens, this hydroponic grower was arrested and he was held responsible for the 2,000+ plants seized in the house. Had he grown 10 plants per lamp (700 plants) instead of a mean of 30 under the 70 lamps installed in the greenhouse, perhaps his jail sentence of four years would have been shorter. This is suggested by Plecas et al.'s (2005) study which found a significant, positive correlation (r = .17, .05 level) between jail time and the number of plants seized in British Columbia, Canada.

9. These growers start their plants in September to harvest a first crop in December, a second in March, and a last one in June, before the outdoor season.

10. Growers also reported wanting to take a break from the constant surveillance required by indoor cultivation, and others mentioned that the important drop in wholesale cannabis prices after the outdoor harvests (September-October) do not make summer indoor growing worthwhile.

11. Online seedbanks now offer special seeds, (feminized seeds), that are assumed to greatly reduce the possibility of finding male plants. This innovation is recent enough that it should not be taken into account for the current study, which is concerned with estimating cannabis production for the year 2002. Moreover, only one grower mentioned the existence of feminized seeds, but he never used them himself.

12. It is also important to point out that many outdoor growers, even if they use seeds, start their plants indoor during in February or March. When the plants are moved into ground in June, the male plants have already been discarded.

13. Notice that the key parameters for estimates 2 and 3 only concern indoor and hydroponic cultivation sites. Thus, all three estimates will use the yield-per-plant parameter to estimate outdoor cannabis production.

14. I used two regression formulas, one for outdoor sites, and one combining indoor and hydroponic sites. For outdoor sites (N = 9): Y =

2.124 – 0.00532*P, where Y is the yield per plant (on oz) and P is the number of plants grown per site. For indoor and hydroponic sites (N = 23): Y = 1.306 – 0.000587*P.

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Appendix L: Plecas et al. (2009) Commercially Viable Indoor Marihuana Growing Operations in British Columbia: What Makes Them Such a Serious Issue?

COMMERCIALLY VIABLE INDOOR MARIHUANA GROWING OPERATIONS IN BRITISH COLUMBIA: WHAT MAKES THEM SUCH A SERIOUS ISSUE?

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ABSTRACT

While cases of large-scale illicit indoor marihuana production in British Columbia have become commonplace in media reporting, there is little detailed information the many facets of harm posed by this illegal industry. This article brings together what is currently known about the impact of the marihuana production industry to answer some of the most pressing questions facing policy makers, prosecutors, law enforcement, and the general public on this topic. With an emphasis on those growing operations intended for profit within the illegal drug trade, this article demonstrates the seriousness of this increasingly large, sophisticated, and pervasive type of criminal activity.

Keywords: Marihuana; Drug Production; Health Risks; Social Problems; Illegal Drug Markets; Commercial Viability

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INTRODUCTION

Media reports of law enforcement efforts targeted at marihuana growing operations or 'grow ops' in British Columbia has come to be so common in recent years we can appreciate why many people might have started taking them for granted. Indeed, any new media report about grow ops almost seems like old news. Further, while these reports will from time to time give attention to the violence, organized crime activity, and other harms associated to one aspect or another of marihuana industry in the province, few of them really get into the details. Consequently, most British Columbians might have some sense that marihuana growing operations are a problem, but they do not get a level of the information that would be helpful to fully appreciating why grow ops in British Columbia are an extremely serious matter.

The issue of grow ops is also commonly linked to the very public and long-standing debate about the de-criminalization of marihuana, with its adjoining suggestions that marihuana is a benign drug, and that organized crime and the associated violence would largely disappear if government authorities would simply remove the criminal status of marihuana possession and production. Accordingly, attention regarding the seriousness of the matter of marihuana grow ops is often overshadowed by arguments that the only reason marihuana grow ops are a problem is because of the way the government has chosen to look at them.

With the above in mind, and in the spirit of making more detailed information available, the purpose of this report is to call attention to what we have come to know about the harms associated to marihuana grow operations. Further, the purpose is to provide information about the number and commercial viability of grow operations so as to give the reader an appreciation that growing operations in British Columbia are not primarily so called "ma and pa" personal use operations, but rather highly profitable investments collectively contributing to a multi-billion dollar and largely export illicit drug industry.

The report is organized in a question and answer format. This format was selected to provide straightforward answers to some of the most pressing questions related to marihuana production that face policy makers, prosecutors, law enforcement, and the public as a whole. The report looks first at why marihuana use should be of concern to British Columbians. The question is relevant of course, because there would be less reason to care about growing operations if the product being produced was harmless. Subsequent sections focus specifically on questions related to indoor marihuana cultivation, first addressing the potential harms, and then providing information on the nature of the marihuana industry. Through the answers to following questions, we hope to emphasize why indoor marihuana growing operations should be considered an issue of great concern, and one which requires further effort to properly address.

WHAT ARE THE HARMS OF MARIHUANA USE?

Through a recent review of the current literature on marihuana use (Diplock, Cohen, and Plecas, 2009), we concluded that marihuana poses some considerable risks to users. There are a number of serious risks to users of the drug, specifically when it is smoked. Those risks related to a user's health are perhaps of most concern. Smoking marihuana can cause considerable harm to the lungs and airways. The inhalation of marihuana smoke can lead to common respiratory ailments such as coughing on most days, wheezing, shortness of breath after exercise, nocturnal chest tightness, chest sounds without a cold, early morning phlegm and mucus, and acute and chronic bronchitis which may affect as much as 40% of the user population (Moore et al., 2005). Additional harms can occur to the user's immune system, potentially inhibiting the ability of the lungs to defend against foreign pathogens (Shay et al., 2003). Currently, the link between marihuana use and cancers has not been confirmed by research, but since marihuana smoke contains many of the same carcinogens as tobacco smoke, the plausibility of an association should be a concern (Mehra, Moore, Crothers, Tetrault, & Fiellin, 2006). Additional health concerns such as heart problems and threats to human reproduction are not common among marihuana users, but the risks should not be dismissed (Diplock et al., 2009).

Marihuana use is associated to risks related to the overall lifestyle of users. The development of psychosis and later schizophrenia has recently been recognized as a serious risk for a small proportion of those who use marihuana (Arendt, Rosenberg, Foldager, Perto, & Munk-Jorgensen, 2005; Degenhardt & Hall, 2006). It is unknown whether marihuana is a causal factor for these types of mental illness or a trigger for those already predisposed, but there is a general consensus that the use of the drug is associated to these mental afflictions (Raby, 2009). Dependency is also a real risk for some users (Hall, 2006; Looby & Earlywine, 2007). Academic performance and social development appear to be negatively affected by marihuana use (Lynskey & Hall, 2000), but the literature did not confirm a causal role for marihuana use in the lack of future success of young people (Schuster, O'Malley, Bachman, Johnson, & Schulenberg, 2001). Furthermore, findings regarding the drug's ability to cause short-term impairment, specifically to negatively affect driving ability (Bedard, Dubois, & Weaver, 2006), should be a concern to users and others. All of the harms discussed may be compounded by the fact the marihuana users have an increased likelihood of continuing on to other illicit drugs (Fergusson, Boden, & Horwood, 2006; Lynskey, Vink, & Boomsma, 2006).

While the most serious of the harms discussed here are not experienced by the majority of users, marihuana use is associated to health problems that range from those that might be considered minor to those that are life altering. It is important to recognize that marihuana is neither harmless, nor is it particularly dangerous to the majority of users. However, given that marihuana is a widely used substance, it must be acknowledged that the lives of a small proportion of the population will be seriously disrupted by marihuana use.

WHAT ARE THE POTENTIAL ECONOMIC COSTS OF MARIHUANA USE?

The risks associated to marihuana use are likely to translate into economic costs in terms of health care expenditure and loss of productivity. Given that marihuana is commonly used in British Columbia, with approximately 16.8% of the population of those 15 years old and over using marihuana in a given year (Stockwell, Sturge, Jones, Fischer, and Carter, 2006), even if only a small portion of the user population is afflicted by serious health problems, the associated costs put increased pressure on our health care system and consequently on tax payers. Therefore, the harms of marihuana use cannot simply be understood in terms of potential risks to only the users themselves, but instead that the burden of marihuana use is faced collectively by all British Columbians.

Despite a belief among many users that the effects of marihuana smoking are benign compared to the widely accepted consequences of tobacco use, experts emphasize that marihuana smoking should be viewed as at least as harmful as tobacco, specifically to the lungs (Taylor & Hall, 2003). According to Bridge and Turpin (2004), tobacco smoking cost British Columbians $525 million annually in 2002, and an additional $904 million in productivity losses for the 542,240 tobacco smokers in the province. Using the 16.8% figure reported by Stockwell et al. (2006) in conjunction with population statistics for 2004 (BC Stats, 2009)[2], we can approximate the number of marihuana users in the province during that year at 580,541. That number is even greater than the number of tobacco smokers in 2002 reported by Bridge and Turpin (2004). Although, the average marihuana user smokes less regularly than the average tobacco user, some researchers (Aldington et al., 2007) suggest that each marihuana joint can have the obstructing effect of five tobacco cigarettes. Other research indicated that marihuana smokers generally show comparable

[2] There were 3,455,602 British Columbians aged 15 and over in 2004.

respiratory symptoms to tobacco smokers, but with much shorter smoking histories (Moore et al., 2005). In addition to some of the health consequences that marihuana smoking shares with tobacco smoking, marihuana use may be a factor in psychosis and later schizophrenia. The increased costs for mental health care and loss of productivity from these mental illnesses have the potential to raise the annual costs associated of marihuana use above those projected for tobacco smoking.

Because many marihuana users are also tobacco smokers and some may also partake in other unhealthy choices, it is difficult to estimate the extent to which marihuana use alone has put an economic burden on British Columbians. Despite this difficulty, it is apparent that marihuana use does put an added economic strain on British Columbia's health care system, tax payers, and the province's legitimate economy as a whole, potentially in the range of hundreds of millions of dollars. This is of particular concern since the illegal marihuana production industry is fuelling these problems while remaining free from taxation.

WHAT ARE THE DANGERS OF INDOOR MARIHUANA PRODUCTION?

The illicit nature of marihuana growing ultimately leads those who undertake in these operations to hide their activities from the authorities and the public. In order to avoid detection, along with other reasons, marihuana growing operations are often located indoors, in homes and other buildings that require substantial changes to make the environment suitable for growing. Although not all marihuana grow ops are large and sophisticated endeavours,[3] those that operate indoors with the intention of making commercial profit require large amounts of energy (commonly electricity), structural and mechanical changes to the site, pesticides, herbicides, and fertilizers, as well as measures to protect the site from detection. The changes made to facilitate the growing of marihuana involve practices that generally require specific training, certification, and inspection to ensure proper function and safety. The illicit and clandestine nature of marihuana growing

[3] According to estimates of the prevalence of marijuana growing operations in Quebec for 2000-2001 by Bouchard (2007), approximately 20% of indoor marihuana growing operations (both soil-based and hydroponic) involved 20 plants or fewer.

operations prevents the regulation and maintenance of safety standards within these sites. Furthermore, when a marihuana growing site is located within a residential neighbourhood, the risks associated to errors in or abuses of construction, ventilation, chemical usage, waste disposal, plumbing, electrical work, and security are assumed by others without their knowledge and consent.

To determine the nature and extent of the dangers of indoor marihuana growing operations, we elicited the help of a focus group of professionals in the field of environmental consulting and industrial hygiene. According to the focus group, who have seen marihuana grow ops first hand and have been responsible for the remediation process (Surrey Fire Service focus group, July 10, 2009), growing sites have one type of contamination or another in every case. The focus group identified improper ventilation in approximately 90% of growing sites, leading to high levels of relative humidity around 80%. Due to the high levels of moisture within grow ops, individuals within the site are often ultimately exposed to mold.

Growers may also try to improve the yield of their operation by using carbon dioxide (CO_2) and chemicals (Surrey Fire Service focus group, July 10, 2009). CO_2 is used to increase the rate of growth and tolerance to higher temperatures in growing sites. Exposure to higher than normal levels of CO_2 can be dangerous, and the problem may be further compounded when the increase of the gas coincides with displacement of oxygen (O_2). Chemical residues are almost always left behind by marihuana growing operations (Surrey Fire Service focus, July 10, 2009). Fertilizers are a common cause of these residues, as are herbicides and pesticides in more advanced grow ops. According to the focus group (Surrey Fire Service focus group, July 10, 2009), these chemicals are often found in high concentrations at growing sites, along with signs of spillage and on-site dumping. In testing residual pesticides in former growing operations, Blair and Wedman (2009) found the presence of 15 different pesticides used in 139 homes. The average levels found for the two most common pesticides were just below and just at the acceptable safe level, although the maximum levels found for most chemicals found were above a safe level (Blair & Wedman, 2009).

Because indoor marihuana grow ops require a great deal of electricity to power the typically 1000 watt bulbs used to provide the plants with light, these operations are susceptible to serious electrical hazards including fire. Garis (2008) outlined many of the electrical hazards common to marihuana growing operations that can increase the risk of fires. These included inadequate electrical protection of fuses and circuit breakers, improper installation of electrical systems, failure to enclose electrical by-passes, and improper monitoring of grow sites (Garis, 2008). Improper installation of electrical systems puts those within the grow site at risk of shock and electrocution, especially considering the high likelihood of the presence of water (Garis, 2008). Electrical by-passes are only one of many electrical hazards that inflate the risk of residential fires in marihuana growing operations to what Plecas, Malm, and Kinney (2005) estimated was 24 times as great as that faced by a regular home[4].

The danger presented to those living within marihuana grow ops is evident, as many of the previously described hazards are present in the vast majority of cases. Of particular concern is that the previously discussed dangers such as high humidity, increased CO_2 levels, high energy light systems, and improper and unregulated construction and electrical work make marihuana grow sites much more hazardous to children than a typical home. Of course, it is difficult to estimate the true number of children who live in and around marihuana growing sites on a daily basis, but it is evident that children have been exposed to the potential harms of marihuana production (Plecas et al., 2005).

These dangers are not limited to only the grow operators, but pose a serious threat to neighbours and first responders. Contamination from the chemicals used in the growing process is a major health concern for people in neighbouring properties. According to the focus group (Surrey Fire Service focus group, July 10, 2009), there is a real risk of drinking water contamination in the neighbourhood as a result of back flushing. Also, the spilling and dumping of chemicals can result in the migration of substances into neighbouring

[4] This figure assumes that those growing operations that did not come to the attention of police had the same likelihood of catching fire as those that did. However, it can be argued that the vast majority of growing operations that caught fire would have been discovered by police, and therefore, the actual risk is much lower. We still maintain that even if only one fifth of all marihuana growing operations came to the attention of police, the probability of a growing operation catching fire is nearly five times as great as that faced by a normal residence.

properties, which would require remediation to eliminate the danger. All of the aforementioned hazards present serious risks to law enforcement, fire crews, and other first responders who may enter the residence without prior knowledge that a grow op exists. Also, there is some indication that booby traps are sometimes (although uncommonly) used by grow operators to dissuade entrance into the grow site, posing another threat to emergency responders (Garis, 2008; Plecas et al., 2005; Surrey Fire Service focus group, July 10, 2009).

WHAT PROBLEMS DO MARIHUANA GROWING OPERATIONS CAUSE IN COMMUNITIES?

In addition to the health risks identified above, there is also the potential for marihuana production to cause social problems to communities. These problems include attracting and supporting criminal activity, lowering property values, increasing living costs, and impacting the environment. These problems may be of most concern for those living within close proximity to marihuana growing operations, but the negative effects of marihuana production influence all British Columbians.

Currently, there are no studies that investigate whether the presence of a marihuana growing operation causes a rise in other types of crimes in the surrounding neighbourhood. However, based on the findings of Plecas et al. (2005), between 1997 and 2003, 9% of all investigations of marihuana production started while responding to another crime, and another 3% began as a result of serving a warrant. These findings indicate that other crime does occur around marihuana growing operations, but whether the presence of the operations is a significant contributing factor for other crime is unknown. Despite a lack of empirical evidence that grow ops increase criminal activity, it is important to note that police sources (Royal Canadian Mounted Police, 2007) insist that marihuana grow ops are a major source of funding for organized criminal groups, many of which use violence to protect their criminal interests.

With organized crime group competing against each other within the drug production industry, it is conceivable and indeed probable that a marihuana growing operation might be the target of a criminal attack. The term 'grow rip' has been used to describe the breaking and entering of a residence which houses a marihuana grow op to either steal or destroy the product of a rival. A brief search of the Canadian Newsstand database for newspaper articles on 'grow rips' allowed for the identification of six individual cases of this type of home invasion between January and May of 2009 in British Columbian newspapers. The cases described in these articles involved groups attacking homes that were found to contain marihuana plants (Baker, 2009a; Freeman, 2009; Hooper, 2009; Zytaruk, 2009a;b;c). Common in these accounts was that violence was used against the occupants of the houses, often involving weapons such as firearms and knives. In one case (Zytaruk, 2009a), five intruders mistakenly invaded a home that they though contained a marihuana growing operation and held two residents captive before leaving. What is alarming is that some organized crime groups have formed with their primary function being to commit home invasions of grow ops.

In addition to the potential for home invasions and other violence to increase as a result of the drug trade, the presence of marihuana growing operations also offers an avenue for young people to become involved in criminal activity. This is especially true for children who are raised in residences housing grow ops, since they are exposed to a lifestyle that includes illegal activities. Research by Bouchard, Alain, and Nguyen (2009) indicated that in some areas the existence of a marihuana cultivation industry provides the opportunity for youth to make money and become involved in crime. From their sample, Bouchard et al. (2009) reported that 12% of youth between age 13 and 17 in a region in Quebec had participated in the production of marihuana in the previous year. It is certainly a possibility that youth in parts of British Columbia are exposed to opportunities similar to of the adolescents in the Quebec community studied by Bouchard et al. (2009). Perhaps the allure of easy money, the access to marihuana, and the excitement of the criminal or gang lifestyle among other enticing factors that surround marihuana production could make marihuana cultivation the starting point in the criminal careers of some young people.

The indoor marihuana growing industry has negative effects that permeate into other aspects of society, influencing the lives of even those who may not be seem directly affected. Perhaps most problematic is the fact that, in many places, it may not be a safe assumption that indoor marihuana growing is not occurring nearby. Based on calculations by Bouchard (2007), the risk of detection in one year for indoor marihuana growing operations in Quebec was less than 10%, even for the largest operations. If the large majority of grow ops go on undetected, this implies that there may be many contaminated residences that used to be former growing operations. The stigma of a past marihuana growing operation can greatly reduce the value of a property, and with the relatively low chance of detection, there have likely been a number of sales of former growing operations in the province that have gone undisclosed. In addition to the health and safety hazards associated to any tampering or leftover mold and chemicals, our focus group (Surrey Fire Service focus group, July 10, 2009) reports that the future discovery of those hazards will force the new owner to incur an expense around $25,000, which may increase depending on the extent of the contamination and the cost of additional repairs.

Even for those who do manage to avoid living near or buying a home that used to house an indoor marihuana growing operation, there are economic and environmental costs that affect everyone. One such example may be in the housing market, where home buyers are competing with prospective marihuana growers to purchase property. Not only are drug producers damaging and devaluing homes for future owners, but they may also be driving up the costs with the demand for new drug production sites. In cities where housing issues are a high priority, the use of family dwellings to produce illegal drugs should be a major concern.

Another example involves the economic and environmental costs of the electricity required to power the abundance of illegal marihuana growing operations. Based on the data from 2003, the average marihuana grow op in British Columbia had 15.5 lights[5] (Plecas et al., 2005). Assuming a growing cycle involves at least 18 hours of light each day for the first month, followed by two months of 12 hour per day, a grow op uses an average of 14KWh per day for each light over the course of a crop. This suggests that the average grow op uses 217 KWh each day, totalling 78,120 KWh over a year for lights alone. At a cost of $0.06 per KWh, the average operation uses $4,687.20 worth of electricity each year.

[5] According to Garis (2008), the most common lights used by growers were 1000W.

Estimates reported by Garis (2008) indicated that marihuana production accounts for more than 6% of the electricity supplied to residential customers in British Columbia, a total cost of more than $60 million per year. Reiterating the sentiments from that study (Garis, 2008), it is a serious concern that those within the indoor marihuana production industry consumes a highly disproportionate share of a valuable resource.

Of course, since marihuana production is often associated with electricity theft and the profits from the sale of the illegal product are not subject to taxation, grow ops amount to a considerable drain on the provinces resources and tax payers. In 2003, the average size of a grow op with a hydro-bypass to steal electricity was 28 lights. Therefore, the amount of electricity stolen by the each of the approximately 20% of marihuana growing operations[6] is about 141,120 KWh with an annual value of $8,467.20. The electricity consumption of the marihuana production industry in this province raises the costs of this resource for all consumers and, if the consumption patterns continue or increase, will result in the need for more energy producing dams and power plants. In British Columbia alone, it was estimated that the predicted 1,100 GWh per year consumption of marihuana growing operations would be comparable to the power generation of a recently started hydroelectric project estimated to cost $660 million (Garis, 2008).

HOW CAN THE POTENTIAL YIELD OF A MARIHUANA GROWING OPERATION BE ESTIMATED?

Estimating the potential yield of a marihuana growing operation has historically been very speculative. There are a lot of variables to consider when estimating the potential yield of these operations. Previously, estimates of the annual yield of marihuana growing operations have been predominantly based on the number of plants discovered at the growing site and the number of crops that can be produced in a year. As Bouchard (2008) noted, previous estimates tended to be largely exaggerated because the assumptions about the amount of marketable product per plant were inaccurate. Assuming that each of the marihuana plants in an operation could produce anywhere from 1lb to 1 kg

[6] According to Plecas et al. (2005), approximately 20% of growing operations involved a hydro-bypass.

(2.2lbs) greatly over estimates the potential yield of a marihuana growing operation. We have determined that even the 100 grams per plant estimate originally used by Plecas, Dandurand, Chin, & Segger, (2002) has now been determined to be an over-estimate.

Although the estimates for the amount of marketable product per plant have historically been overstated, researchers trying to understand illegal marihuana production have generally had a strong understanding of the number of crops that can be produced each year. In his estimates, Easton (2004) used the figure of four crops annually for a 100 plant operation. This reflects the figure used by Bouchard (2008), who suggested that large operations (more than 100 plants) would generally produce four crops, while medium and small operation (20 to 100 plants and 1 to 20 plants respectively) would produce three crops. Outdoor operations of any size were estimated to produce only one crop (Bouchard, 2008). For the remainder of this report, we are going to estimate that a grow op for personal use will produce three crops annually and one intended for profit will produce four crops annually.

Recent research from Toonen, Ribot, & Thissen (2006) reported that the yield per plant was 33.7 grams and that generally 15 plants were grown around a single lamp. These findings reflect the general consensus of growers and other researchers (Bouchard, 2008), and would present a better alternative to other grams per plant estimates. However, as much of the yield depends on the amount of light received by each plant, the yield of 33.7 grams per plant may only be accurate for those grow ops that are configured in a similar way with 15 plants around each lamp. Also, as even the best growers experience plant attrition at some time prior to harvesting the crop (Bouchard, 2008), estimating yield purely based on the number of plants present at a growing site may provide an estimate that is over or under the actual yield. As this is the case, an easier and potentially more accurate way to estimate the yield of a marihuana growing operation is to base the estimate on the number of lights rather than plants.

A grower's 'rule of thumb' that was reported by Bouchard (2008) which also reflects information provided to us by our contact, Brian Carlisle[7] (personal communication, October 1, 2009), is that the predictable yield for a marihuana growing operation can be approximated at 1 lb per active light each crop. As 1 lb is the equivalent of 454.5 grams, this easy 'rule of thumb' provides a conservative estimate that generally reflects the yield data from the studies of both Toonen et al. (2006) and Bouchard (2008). For the remainder of this report, estimates of the potential yield of marihuana growing operations will rely on the assumption that a light produces 454.5 grams each crop. Furthermore, the authors suggest that 1 lb per light estimate would provide an improved standard that can be adopted by criminal justice policy makers, law enforcement officers, crown prosecutors, and judges when dealing with cases of indoor marihuana production.

WHAT IS NEEDED TO SET UP AND MAINTAIN A MARIHUANA GROWING OPERATION?

The setting up and maintaining of a marihuana growing operation, especially one intended for commercial viability, has a number of prerequisites, chief among them the ability to fund the operation for a period before profits can be generated. As the start up and maintenance costs are key considerations for determining whether or not an operation of a particular size could be commercially viable, it is important to have an understanding of these costs. To answer this question, we list the required skills and funding for a ten light operation. Although this size of an operation is below the average reported in 2003, the estimated costs of a ten light operation can be used to easily extrapolate the costs for operations of any size. The estimates we use here are set to represent a minimum level of expenditure that when extrapolated would take into consideration economies of scale and increasing levels of sophistication.

With the help of our experienced grower contact, Brian Carlisle, we have listed below the equipment and services necessary to set up a commercially viable grow op along

[7] Brian Carlisle is a very knowledgeable source on the topic of marihuana growing. He is a former medical marihuana grower with 15 years of experience dealing with the market for both illegal and medical marihuana

with the estimated minimum costs associated to each. We concede that some, even the majority, of commercial operations might spend more on some components or use equipment not listed here, but this list is intended to represent the most basic of commercial operations.

Lights – $2500: Every indoor grow op requires lights. In the vast majority of cases in British Columbia, these lights used 1000 W bulbs. We estimate a cost of $250 per light.

Reflectors - $800: To increase the amount of light received by the plants, a reflector is used with each light. Each reflector is estimated at a cost of $80.

Timer - $200: A timer is used to control when the lights turn on and off. For this scenario, only one timer is used, although some operations may use more timers and use them for a variety of purposes. The timer is estimated at a cost of $200.

Wiring and Electrical Set Up - $3000: As residences are not originally intended to house marihuana grow ops, a new growing location will require extensive changes to the electrical system and wiring in order to power the high energy lights. Although there are many cases in which the electrical systems in grow ops are improperly installed, we assume that someone with the skills and training, or at least the experience of an electrician would be required to ensure the grow op could function. To account for the costs of the wiring, electrical panels, and the electrician's labour, we conservatively estimate the setup cost for the ten-light operation at $3000.

Retrofitting Growing Environment - $2000: In order to make the environment suitable for growing, structural changes need to be made to the grow room. The estimate of $2000 includes both supplies and the labour charges of a carpenter or handyman.

Fans - $200: In order to keep the necessary air flow within the grow room, fans are needed. The air movement can also strengthen the plants, allowing them to better support the growth of buds. We estimate two oscillating fans for the grow room at $100 each.

Cooling Unit - $1000: The high energy lights can raise the temperature of a grow room to levels that can jeopardize the plants. In order to keep the temperature at a suitable level, some type of cooling unit is required. We conservatively estimate that a low quality cooling unit (e.g. either a chiller, air conditioner, or heat exchanger) would be an expense of $1000.

Dehumidifier - $100: To reduce the humidity of the growing environment, the operation would require at least one dehumidifier. We estimate the low range cost of a dehumidifier at $100.

Ventilation - $500: Outside air is required to keep the plants healthy, and consequently the indoor air needs to be displaced. By converting existing ventilation or creating new outlets for the grow op, we conservatively estimate the costs of venting at $500.

Charcoal Filter - $100: To avoid the smell of growing marihuana escaping through the ventilation port, a charcoal filter would need to be installed. We estimate a charcoal filter for one outward vent at $100.

CO_2 - $200: Carbon dioxide is widely used to improve the growing condition. A machine for increasing the carbon dioxide levels in the grow room is estimated at $200.

Pots - $200: With 15 plants around each light, the ten-light operation would require 150 pots in which to grow the plants. We estimate the cost for three 5 gallon pots at $4.00.

Soil - $300: With approximately 15 plants around each light, a ten light operation would require soil for about 150 plants. Although not all growing techniques require soil, for the purpose of this estimation we assume a soil-based operation. With each plant in a 5 gallon pot, we estimate that a 50 gallon bag of growing soil would cost $20, creating an expense of $300 for the necessary 15 bags.

Herbicides & Pesticides - $150: To protect the crop from potentially harmful pests, a supply of chemicals would likely be on site to be administered in the case of infestation. Based on the information from our focus group on the hazards of marihuana growing operations and the research of Blair and Wedman (2009), we know that the use of herbicide and pesticides in growing operations in not uncommon. We estimate the cost the necessary amount of chemicals for a ten light operation to be $150.

Clones - $750: The marihuana plants intended to be grown and harvested have to come from somewhere. Although the plants can be grown from seeds, it is most likely that commercial growing starts with clone plants purchased from another illicit source. We estimate that a tray of 50 clones would cost $250. The expense incurred from three trays is $750. We include this as a setup cost because we assume that additional clones can be taken from a mother plant from the first crop, but we acknowledge that some operations may choose to buy new plants for each crop.

The accumulation of all of the previously listed expenses adds up to a setup cost of $12,000 for the ten-light operation. In addition to these initial costs, a marihuana growing operation can incur considerable ongoing expenses. These include the rent or mortgage payments for the location, the electricity to run the growing lights and equipment, the nutrients for the plants, and additional bulbs and other supplies. Ongoing costs can be greatly reduced if the grow operator steals electricity or generates it onsite. Also, for those growers who do not have to rent or buy an additional property specifically for the purpose of marihuana production, the costs associated to the grow op are again reduced. However, we still estimate that ongoing costs for the supplies necessary to maintain a ten-light operation at around $1000 per crop.

WHAT IS A COMMERCIALLY VIABLE MARIHUANA GROWING OPERATION?

Marihuana production can be a lucrative illegal endeavour, but not all cases of marihuana cultivation are intended to turn a profit. Smaller operations intended for personal use are illegal and are still a concern, but those operations that are intended for large profits present greater risks and are a main source for the illicit drug trade. Therefore, it is important to have the ability to distinguish between those marihuana growing operations that are for personal use and those that are designed specifically to be commercially viable.

The concept of commercial viability in the marihuana production business is likely something that has changed over time. As innovative detection techniques are developed and used by law enforcement, a grower's need for security and counter-detection strategies increase. What was required for a profitable marihuana growing operation in the late 1990s or early 2000s have no doubt changed somewhat from what is currently necessary in order to compete in the illegal market. The changing reality increases the costs of doing business and thus may force some growers out of the market, leaving marihuana production an industry predominated by high quantity producers who are very sophisticated and extremely competitive.

However, the marihuana growing operations that are intended for personal use may not differ from those that have existed historically. Since grow ops for personal use are separated from the larger illegal production and distribution industry and the chance of detection is generally much lower for small size operations (Bouchard, 2007), it is likely that the factors that may be forcing small and mid-sized commercial operations out of business would have little to no affect. If this is an accurate representation of current progression in the illegal marihuana production industry, it should become increasingly easier to distinguish between those operations that are commercially viable and those that are mainly for personal use.

In the meantime, however, to determine whether a grow op is or was intended for profit, it is important to explore two main factors. The first is how much marihuana is needed for personal use. If a grower is only growing enough for his or her own consumption, the number of plants and lights used in the operation should reflect that purpose. According to data from the 1991 National Household Survey on Drug Abuse (Gfroerer, Gustin, Virag, Folsom, & Rachel, 1991), the average marihuana user consumes the drug at a rate of 281 joints per year. A joint ranges between 0.5 and 1 gram[8] (Easton, 2004); therefore, the consumption for an average user would be between 11 - 23 grams per month, or 140.5 - 281 grams per year. Health Canada (2008) recognizes that most users of medical marihuana will consume 1 to 3 grams of dried marihuana per day. Consumption at the upper range for these users would require a supply of 1.095 kilograms per year.

[8] In general, the average marihuana smoker would likely smoke a half gram joint, while more frequent or 'chronic' users might larger joints of one gram. For the purpose of estimations later in this report, we assume the average joint to weigh 0.515 grams.

From the previous discussion of the yield of marihuana growing operations, it was concluded that a grower will generally produce 1lb or 454.5 grams per light for each crop harvested. Assuming that the grow op for personal use produces three crops annually, a one-light operation might yield 3 lbs (1.3635 kg) of dry marihuana each year. That roughly translates to the amount of marihuana used by those medical users in the upper range of Health Canada's (2008) figure for a period of 15 months. It is almost ten times more marihuana than the 140.5 grams smoked by the average user.

Given that the potential yield of a one light operation would be more than ten times what an average marihuana users might consume in a year, it would be fair to suggest that an operation consisting of more than one light has the potential produce more than what is needed for the average user. However, given that dried marihuana may not have a shelf life that lasts the period between each crop, it could be argued that an operation intended only for personal use may use four lights, each used to grow a crop that can be harvested at a different time. After operating for four months, the potential yield would still be around 12 lbs (5.454 kg) annually, but could produce a fresh 1 lb harvest each month. This potential annual production translates to more than 30 half-gram joints per day, nearly five times the yearly consumption of the medical user and nearly 40 times that of the average users.

Of course, the 1 lb per light approximation might be better suited for estimating the potential production of larger operations that are intended to make profit. It is possible that a grower with a few-light operation is not trying to produce to the 'rule of thumb'. This might be a necessary consideration that factors into the discretion of whoever needs to assess whether the operation is indeed intended for personal use. However, the fact still remains that the potential yield of the grow op is around the range of 1 lb per light or higher regardless of the grower's current skill or intentions. In conclusion, a very inclusive criterion for grow ops intended for personal use might be an operation with four or fewer lights.

The second factor in whether a marihuana growing operation is commercially viable is whether or not the potential for profit is larger than the costs incurred through set up and maintenance. Easton (2004) estimated the costs of running a 100 plant marihuana growing operation at approximately $24,500, and earning around $76,000. Easton assumes a 50 / 50 split of the revenue between an investor and an operator, suggesting that the investor nets $13,600 over the year. His calculations demonstrate how even with such a business arrangement, a 100 plant operation was commercially viable in 2000.

For our own analysis we estimate that a grower can sell 1 lb of harvested marihuana for $2000[9]. Table 1 incorporates the estimated costs of setting up and maintaining marihuana growing operations to estimate the potential for profits for grow ops of various sizes. The estimated setup costs were extrapolated from the previously concluded cost of $12,000 for a ten-light operation to an estimated $1,200 per light. Inherent in these estimations is the recognition that quantities of scale would naturally reduce the costs per light for larger operations, but at the same time, with increased size comes a necessity for greater sophistication, and therefore the increased costs associated to greater sophistication may balance out the potential savings. Although we concede that the costs are a conservative estimate, Table 1 demonstrates that if a grower steals electricity and does not have to pay for an added rent or mortgage to house the grow, even a one-light operation has the potential to make some profit. Although a 50 /50 split between an investor and operator was assumed by Easton (2004), this table offers only the overall profit of the operation as a whole. Furthermore, the table does not take into account other costs such as those incurred for extra labour, counter detection, or security, which may be a pivotal expense for those operations that can continue successfully over time.

As the number of plants and the level of sophistication discovered in growing operations in British Columbia between 1997 and 2003 showed an increase (Plecas et al., 2005), there was likely a continuously changing concept of commercial viability. Using our data on grow ops in British Columbia for 2003, more than half of marihuana growing operations had more than 100 plants and the average number of lights used for a grow op was 15.5. While the 100 plant grow op discussed by Easton (2004) may have been the standard for commercial viability for the early years of the 2000s, without the detailed analysis of marihuana growing trends for the latter part of the decade, it may be difficult to

[9] $2000 per lb is consistent with the authors' information from police sources and even lower than the $2600 per pound used by Easton (2004) based on prices in 2000.

assess an appropriate standard for later growing periods. Although the table demonstrates that marihuana growing operations can be very lucrative, especially when the operation involves stealing electricity or generating it onsite, the risks associated to growing marihuana, the extent of a grower's black market connections, and the potential for added expenses are all further considerations necessary to assess whether an operation of a specific size is indeed commercially viable. However, it should also be emphasized that the value of the profits is considerably higher when one considers that it is accumulated tax free. Despite the uncertainty with regard a definitive answer on what represents a commercially viable grow op, what can be concluded is that even for very large operations, the setup costs are such that it is highly unlikely that such an operation would ever be intended for only a single crop.

HOW MANY MARIHUANA GROWING OPERATIONS ARE IN BRITISH COLUMBIA?

Presently, the number of marihuana growing operations in British Columbia cannot be known with any great certainty. The extent of marihuana production in the province must be estimated based on the information from available sources. Police information on the number of marihuana growing operations attended and dismantled is the most common source from which to base estimations of the true number of operations in the province. However, in recent years, some communities around the province have implemented non-traditional enforcement responses, namely Electrical and Fire Safety Inspection Initiatives (EFSI), to actively deal with some cases of suspected marihuana growing operations (Garis, 2008; Girn, 2007). Information from these EFSI teams presents an additional source for estimations of the extent of marihuana production.

Using the data from Plecas et al. (2002) on the number of marihuana growing operations discovered by police in 2000, Easton (2004) estimated the number of active grow ops in that year to be approximately 17,500. The number of founded grow ops decreased from over 2,800 in 2000 to just over 2,000 in 2003, potentially as a result of fewer active grow ops. Since the value to cost ratio (1.5) used by Easton (2004) is consistent with the findings from Table 2[10], his formula can also be used to estimate the number of active grow ops in the province in 2003. Changing only the number of founded grow ops, Easton's method estimates that a total of 12,500[11] active grow ops in British Columbia in 2003. Again, without the detailed analysis of founded cases of marihuana production from 2004 to the present, a similar estimation of the number of active grow ops during latter years of this decade would only be tentative.

Bouchard (2007) proposed a method of estimating the actual size of the marihuana cultivation industry called a capture-recapture model. He estimated the annual number of marihuana growing operations in the province of Quebec to be approximately 13,000 for the years 2000 and 2001. As Bouchard's (2007) method is based on arrests for marihuana production and requires the average number of co-offenders per grow op, the method cannot be exactly replicated using our data on grow ops in British Columbia. Furthermore, Bouchard (2007) categorized marihuana growing operations by size, providing different specifications for each category. However, by inputting our data for the year 2003 into Bouchard's model, the resulting annual number of all sizes and types of marihuana growing operations comes to 11,500.[12] Although, the data may not fit well with Bouchard's model since it provides only a one-year window for recapture, the estimate is not too far removed from the one obtained using Easton's method.

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[10] Assuming the same 50/50 split between an investor and a grow operator, the ratio of value to cost (PQ/C) for the growing operations described in Table 2 ranged between 0.35 for a 1-light operation and 1.91 for a 1000 light operation. The ratio of value to cost (PQ/C) for the average 15.5 light growing operation was 1.41.

[11] Easton (2004) estimated the number of marihuana growing operation using the formula $T = B[1+PQ/C)]/[(PQ/C)-(1+R^*)$, where T is the total number of growing operations, PQ/C is a ratio of value to cost = 1.5, R^* is the assumed return to legal activities, and B is number of founded marihuana growing operations discovered by police during the year.

[12] Bouchard's (2007) model used the formula $S=\sum(Z_i/C_i)\lambda_{i,n}$, where S is the total number of growing operations, Z is the estimated number of growers for each type i, C is the number of co-offenders required each type i, λ is the proportion of seizures of each type i and sizes n. To use this model, we did not separate the growers by type or the growing operations by size, adopting the formula S=Z/C. C was calculated using Easton's formula C=2.955 + 0.0057*p where p is the average number of plants seized per grow (p=208 in 2003). Z was estimated using Bouchard's capture-recapture model $Z=N/(1-e^{(-2*n_2/n_1)})$ where N is the number of individuals arrested, n_1 is the number of individuals arrested once, and n_2 is the number of individuals arrested twice. From the data of Plecas et al., (2005) N was 1,670 persons in 2003, n_2 was 26 persons, and n_1 was 1642. Z=53,572 and S = 11,494. Bouchard's model used a period of three years to assess capture and recapture then divided by three to determine the population of offenders for a single year. Limitations in the data prevented we from uses a three year period for the calculation of Z.

For the purpose of this report, we propose that an estimated 10,000 commercially viable marihuana growing operations were active around the year 2003. This estimate is based on information provided by BC Hydro (presentation to EFSI/PSIT Regional Meeting, District of Mission, B.C., Sept. 2009) that approximately 16,000 residential accounts were using electricity at a rate of more than the 93 KWh per day, the threshold for inspection define by the British Columbia's Electrical Safety Regulation (Safety Standards Act, 2004). Not all cases of high consumption are the result of an illegal marihuana growing operation, but a conservative estimate puts the proportion at 50% (discussion at EFSI/PSIT Regional Meeting, District of Mission, B.C., Sept. 2009). Furthermore, based on findings from Plecas et al. (2005) that on average 20% of marihuana growing operations exhibited signs of electricity theft, this implies an additional 2,000 operations were stealing electricity. With 8,000 residential operations identified through over-consumption and another 2,000 assumed to be stealing, we estimate that 10,000 commercially viable growing operations[13] were active in British Columbia in 2003. This estimate is below the 17,500 proposed by Easton (2004) for the year 2000 and the 2003 estimates reached following the methods of Easton and Bouchard. With growing sophistication and a likelihood that more operations are stealing electricity or providing power onsite, the current number of commercially viable marihuana growing operations may be much greater than the 10,000 suggested here. However, we are confident in concluding that for the period between 2000 and the present, the number of active commercially viable marihuana growing operations in any one year was not below 10,000.

HOW MUCH MARIHUANA IS PRODUCED BY BRITISH COLUMBIA'S COMMERCIALLY VIABLE MARIHUANA GROWING OPERATIONS?

Estimating the entire marihuana production in British Columbia requires the answers to many of the previously discussed questions. It requires an ability to estimate the yield of a marihuana growing operation, knowledge of size of operations, and a figure to

[13] As the 93 KWh threshold for over-consumption does not capture those operations with fewer than 5 – 6 lights (assuming 14 KWh per day for each light), and the average case of electricity theft involved 28 lights, this estimate conservatively reflects the number of commercially viable growing operations and is unlikely to include those small growing operations intended for personal use.

other parts of Canada and the United States. Research by Stockwell et al. (2006) indicated that about 16.8% of British Columbians aged 15 and older had used marihuana in 2004. Given that BC Stats (2009) reports that there were 3,455,602 British Columbians aged 15 and over in 2004, we can estimate that there were 580,541 marihuana users in the province during that year. As previously mentioned the average user smokes 281 joints per year (Gfroerer et al., 1991). If the average user smokes joints weighing 0.515 grams, British Columbia's domestic consumption in 2004 was approximately 84,040 kg (184,888 lbs).[14] Assuming the province's annual production in 2004 was in the range of 620,000 lbs, the domestic consumption represents only about 30% of the total commercial product, leaving 70% to be exported elsewhere. As our estimate of commercially produced marihuana does not take into account those operations intended for personal use, it is probable that the domestic consumption of commercially produced marihuana is even less than the estimate provided here. In conclusion, a substantial amount of British Columbia's commercially produced marihuana leaves the provincial borders, suggesting that our local problems with marihuana growing operations have a considerable impact on the drug situations in other jurisdictions.

WHAT IS THE VALUE OF BRITISH COLUMBIA'S MARIHUANA?

The revenue generated by British Columbia's commercial marihuana production industry is approximately $1.24 billion. Inherent in this figure is the assumption that the marihuana is sold by the pound at $2000/lb. We present this figure as a conservative estimate of the amount of money that British Columbia's marihuana growers generate from the sale of their product. However, we recognize that when the activities of the broader marihuana market are taken into consideration, the $1.24 billion figure increases substantially.

The price of British Columbia's marihuana varies depending on where it is sold and in what quantity. The potential retail value of British Columbia's marihuana sold on the

[14] As 16.8% of 3,455,602 provides a figure of 580,541.136 annual marihuana smokers, the estimated domestic consumption presented here is slightly higher than the 84,013 kg (184,829 lbs) that would be calculated if the 580,541 figure was used.

estimates here, we have tried to be deliberately conservative at each step of the assessment. We present what can be viewed as the lower limit of what is a very large problem in British Columbia and elsewhere. We would expect the law enforcement and public safety officials who are close to the problem on a daily basis could give reason to be much less conservative.

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Table 1: Estimated Potential Profits of Marihuana Growing Operations of Various Sizes

			Ongoing Expenses			Profit After 1 Crop				Profit After 1 Year			
Lights	Earns / Crop	Set up Cost	Supplies / Crop	Hydro / Crop	Rent*/ Crop	Paying Hydro & Rent	Stealing Hydro	No Rent	Stealing Hydro & No Rent	Paying Hydro & Rent	Stealing Hydro	No Rent	Stealing Hydro & No Rent
1	$2,000	$1,200	$100	$75.60	$2,400	-$1,775.60	-$1,700.00	$624	$700	-$3,302.40	$4,000	$6,097.60	$6,400
5	$10,000	$6,000	$500	$378.00	$2,400	$722.00	$1,100.00	$3,122	$3,500	$20,888.00	$29,600	$30,488.00	$32,000
10	$20,000	$12,000	$1,000	$756.00	$3,600	$2,644.00	$3,400.00	$6,244	$7,000	$46,376.00	$60,400	$60,976.00	$64,000
15	$30,000	$18,000	$1,500	$1,134.00	$3,600	$3,766.00	$6,900.00	$9,366	$10,500	$77,064.00	$92,400	$91,464.00	$96,000
50	$100,000	$60,000	$5,000	$3,780.00	$3,600	$27,620.00	$31,400.00	$31,220	$35,000	$290,480.00	$316,400	$304,880.00	$320,000
100	$200,000	$120,000	$10,000	$7,560.00	$4,800	$57,640.00	$65,200.00	$62,440	$70,000	$590,560.00	$635,200	$609,760.00	$640,000
250	$500,000	$300,000	$25,000	$18,900.00	$12,000	$144,100.00	$163,000.00	$156,100	$175,000	$1,476,400.00	$1,588,000	$1,524,400.00	$1,600,000
500	$1,000,000	$600,000	$50,000	$37,800.00	$24,000	$288,200.00	$326,000.00	$312,200	$350,000	$2,952,800.00	$3,176,000	$3,048,800.00	$3,200,000
1000	$2,000,000	$1,200,000	$100,000	$75,600.00	$48,000	$576,400.00	$652,000.00	$624,400	$700,000	$5,905,600.00	$6,352,000	$6,097,600.00	$6,400,000

*Rent was estimated to conservatively reflect the price for required space, assuming each light required at least 25 ft^2. For five or fewer lights, the estimate assumes at least a two bedroom apartment for $800 monthly. Between 10 and 50 lights assumes an average house with around 1,800 ft^2, costing $1,200 monthly. For 100 lights and larger, the figure of $185/$ft^2$ was used to determine the cost of a house large enough for the operation. The rent for these operations was calculated assuming an added 5% and monthly payments over 25 year.

Appendix M: Bouchard (2007) A Capture-Recapture Model to Estimate the Size of Criminal Populations and the Risks of Detection in a Marijuana Cultivation Industry

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ORIGINAL PAPER

A Capture–Recapture Model to Estimate the Size of Criminal Populations and the Risks of Detection in a Marijuana Cultivation Industry

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Abstract Originally developed in biology, capture-recapture methodologies have increasingly been integrated into the study of human populations to provide estimates of the size of "hidden populations." This paper explores the validity of one capture-recapture model—Zelterman's (1988) truncated Poisson estimator—used to estimate the size of the marijuana cultivation industry in Quebec, Canada. The capture–recapture analysis draws on arrest data to estimate the number of marijuana growers "at risk of being arrested" for a period of five years (1998–2002). Estimates are provided for growers involved in two different techniques: (1) soil-based growing, and (2) hydroponics. In addition, the study develops an original method to estimate the prevalence of cultivation sites "at risk of detection." A first set of findings shows that the cultivation industry is substantial; the estimated prevalence of growers compares to estimates of marijuana dealers in the province. Capture–recapture estimates are also used to compare the risks of being arrested for different types of offenders. Results indicate that hydroponic growers—those involved in large scale and sophisticated sites—face lower enforcement-related risks than growers involved in smaller enterprises. The significance of these findings is discussed in the context of the widespread development, both in Europe and in North America, of a successful domestic production-driven, rather than importation-driven, marijuana trade.

Keywords Marijuana cultivation · Risks of arrest · Risks of detection · Size of criminal populations · Capture–recapture methodologies

Introduction

The organizational structure of the marijuana trade has undergone a series of transformations since the end of the 1970s. Whereas marijuana used to be mainly imported from

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foreign sources to industrialized nations such as Canada or the United States, a large share of marijuana supply is now produced domestically. Available estimates indicate that over 50% of the available marijuana in the United States is of domestic origins, making the country its own main marijuana supplier (Chalsma and Boyum 1994; National Drug Intelligence Center [NDIC] 2004). The proportion of domestically produced marijuana may be even more substantial in Canadian markets, as the country is assumed by police sources to be self-sufficient (Royal Canadian Mounted Police [RCMP] 2004). The RCMP (2004) reported that close to 95% of marijuana seized in Canada in 2003 was of domestic origins. Although the cultivation industry now appears well established in Canada, arrest data indicate that major developments are still very recent. Marijuana cultivation offenses in Canada increased substantially in the late 1980s and especially in the 1990s (Plecas et al. 2002). The number of cultivation offenses increased from 668 in 1980, to 1334 in 1990, and to 9041 recorded offenses in 2000 when it nearly surpassed the number of (10,686) drug selling offenses (Canadian Center for Justice Statistics 2001).

Such seemingly rapid and extensive changes in the organization of an illegal industry are uncommon, and raise important questions about our understanding of how the marijuana trade is structured. A first set of questions concerns the size of the cultivation industry, not only as measured in dollar turnover rates (Wilkins et al. 2002a; Caulkins and Reuter 1998; Rhodes et al. 2000) but in terms of opportunities for new and existing offenders to enter the illegal trade. In an importation-driven industry, a small population of offenders can supply large markets through regular but relatively infrequent importation of large drug shipments from foreign sources. In a production-driven industry, a large number of producers and growers should supply the same large market through the addition of multiple small marijuana cultivation sites. How many active offenders have found a niche in this new industry, and how do these populations compare to the prevalence of marijuana dealers?

A second set of questions concerns the reasons why offenders have gradually chosen cultivation over importation as a preferred source of marijuana supply. A popular assumption among drug market researchers is that the substitution has been stimulated in response to law enforcement interventions (Chin et al. 2000; Weisheit 1992; Reuter et al. 1988). Domestic marijuana production is considered by these sources as an adaptive and innovative strategy triggered by increases in risks of arrest and risks of detection among importers. Two waves of adaptations are usually identified. The first one dates back to the 1970s, when several major police operations were conducted at the U.S.-Mexican border, which may have increased the risks of detection for imported marijuana (Reuter and Kleiman 1986; Weisheit 1992). Because marijuana is bulky and is sold at low prices, adaptive strategies available to cocaine and heroin smugglers (such as decreasing the size of each drug shipment but multiplying its frequency) are less efficient than producing it domestically (Reuter et al. 1988; Weisheit 1992).

Law enforcement pressure may also have contributed to the development of a second wave of adaptations, from outdoor (soil-based) to indoor (soil-based) marijuana cultivation. According to the limited existing research on marijuana cultivation, large-scale eradication programs were used by the DEA to discourage the early marijuana cultivation industry in the 1980s, situated in outdoor, rural settings (Potter et al. 1990; Hafley and Tewksbury 1995; Weisheit 1992). As suggested by Reuter et al. (1988), growers of outdoor crops likely realized how vulnerable they were to law enforcement and to other risks (thieves, animals, plant diseases), and at least some of them moved to less conspicuous indoor cultivation, which could also be conducted in urban settings. The trend from outdoor towards indoor cultivation has also been noticed in Europe (Jansen 2002; Hough et al. 2003), in New Zealand (Wilkins and Casswell 2003), and in Canada (Plecas et al. 2002).

This risk/adaptation hypothesis provides a reasonable account of the development of the marijuana cultivation industry. But in the absence of macro-level research on the size and structure of the industry, or on the levels of risks that law enforcement agencies are able to achieve, it remains difficult to evaluate its empirical value. Displacement effects are assumed to have occurred, but no studies estimated how these populations of growers are distributed among different techniques, or how they migrate from one technique to another. Whereas substance abuse studies have integrated prevalence measures into their research and found innovative ways of analyzing shifts and trends in consumption (e.g. Caulkins et al. 2004; Rhodes 1993; Brecht and Wickens 1993), no research has been conducted on the supply side of drug markets. Besides, such prevalence measures are needed to monitor the effectiveness of law enforcement efforts. With what is known to date, it remains difficult to answer seemingly simple questions: How risky is growing marijuana compared to selling it? And how are risks distributed between different techniques and locations (indoor, outdoor) and different sizes of operations? Part of the problem is technical: most members belonging to an active population of offenders are never arrested and thus are not available for census, and most cannot be reached through available survey methods used to asses the prevalence of drug use.

Capture–recapture methods have been shown to provide valid measures for various hidden populations. These methods build on the relative importance of a recurring pattern in an observed population (e.g. re-entry into treatment, re-arrest) to infer the proportion of this population that is active, but unobserved in the data. Capture–recapture methods have originally been developed in biology to estimate the size of animal populations (Seber 1973; Schwarz and Seber 1999), but have increasingly been integrated into the study of human populations mainly through epidemiological research. Capture–recapture models have been used extensively in the field of substance abuse to estimate the prevalence of drug users susceptible to treatment in a variety of communities (Bohning et al. 2004; Calkins and Aktan 2000; Hser 1993; Choi and Comiskey 2003; Hickman et al. 1999; Smit et al. 1997; Brecht and Wickens 1993). Following the pioneering analyses of Willmer (1970) and Greene and Stollmack (1981) on general populations of offenders, researchers also used capture-recapture methods to estimate populations of burglars (Riccio and Finkelstein 1985), car thieves (Collins and Wilson 1990), prostitutes (Rossmo and Routledge 1990) and their clients (Roberts and Brewer 2006), illegal gun owners (van der Heijden et al. 2003), and drug dealers (Bouchard and Tremblay 2005). Despite these few promising attempts, the methodology is still not well-known and its applications to criminology are just starting to be explored.

The present study proposes the use of a capture–recapture model—Zelterman's truncated Poisson estimator—to analyze the size of a marijuana cultivation industry situated in a Canadian province (Quebec). Prevalence estimates cover both the number of active growers, and the number of cultivation sites they operate. These separate estimates allow for a comparison of the risks of arrest for growers, and the risks of detection for the cultivation sites, which are types of risks that bear different meanings and consequences for offenders. Estimates are differentiated across three cultivation techniques: (1) outdoor, (2) indoor, and (3) hydroponics. Zelterman's model has been used in a handful of studies in the criminological literature but the model's value and limitations are not well understood (Bouchard and Tremblay 2005; Collins and Wilson 1990; Choi and Comiskey 2003; Smit et al. 1997, 2002; Bohning et al. 2004). In the current study, the model is used on marijuana cultivation data for an extended time period (5 years). Confidence intervals are calculated and goodness-of-fit statistics are provided to assess the relative fit of the model to the data.

Finally, a method is proposed for deriving the number of cultivation sites at risk of detection from the estimated population of growers.

Data and estimation model

Data

Arrest data for marijuana cultivation offenses are needed for the capture–recapture analysis on growers. Assuming a satisfactory prevalence estimate of marijuana growers, a combination of fieldwork data on co-offending patterns for individual cultivation sites and of police data on the size and distribution of cultivation-related seizures can be used to derive the prevalence of cultivation sites.

Arrest data

A population of offenders at risk of being arrested can be estimated from a distribution of arrested offenders for a given offense. The MIP data set (Module d'Informations Policières) which comprises all crime-related incidents in Quebec was used for this purpose. Arrests for which the first or second charge (or most serious charges) was for marijuana cultivation were considered as "marijuana cultivation arrests." These arrests were extracted for the 1997–2003 period. Only those offenders for whom a date of arrest was precisely recorded were selected for the analysis. Because the objective is to uncover the number of re-arrested offenders, "duplicates" had to be avoided. Manual validation of every re-arrest resulted in the elimination of 3.5% of cases. For the seven-year period being studied, there was at least one marijuana cultivation charge in a total of 10,647 cases. These arrests involved 10,204 different offenders, 410 (4.0%) of whom were recidivists, that is, were arrested at least twice for a marijuana cultivation offense between 1997 and 2003. No offenders were arrested more than four times during the seven-year period. Police data classify cultivation offenses according to whether the plants are grown in soil (79% of all arrests) or hydroponically (or soil-less, comprising 21% of all arrests). Soil-based cultivation can be carried out either in outdoor or indoor settings, a distinction that is only made in seizure data. Hydroponic cultivation is always carried out indoors. Unless indicated otherwise, "indoor" will refer to the soil-based technique, and "hydroponic" to soil-less cultivation. The proportions of arrested females (15%), and the mean age of arrested offenders (34 years old) are similar for both cultivation methods, and similar to findings reported elsewhere (Plecas et al. 2002).

Seizure data

A second data set was needed to derive the prevalence of cultivation sites, comprising all the seizures made by the Quebec Provincial Police (QPP) for the years 2000 and 2001 ($N = 3212$). Seizures were classified in three categories: outdoor (65%), indoor (30%), and hydroponics (5%). Compared to the arrest data set, hydroponic seizures were underrepresented. Seizures with no arrests are common to outdoor cultivation cases (only 13.9% of seizures lead to an arrest), which increases the proportion of arrested offenders for hydroponic methods compared to other methods. In addition, all police organizations in the province participate to the MIP data set, whereas the data set on seizures lacks most indoor seizures made by Montreal's police department (SPVM). Hence, the risks of detection

Table 1 Number of seizure cases and median number of plants grown per type of marijuana cultivation site, Quebec, 2000–2001

Type of cultivation site[a]	Median size(# of plants)	Mean annual # of cases[b]	Percent of cases
Outdoor			
Small	9	358	36.8
Medium	45	355	36.5
Large	228.5	259	26.6
Total	36.0	972	100
Indoor			
Small	7	75.5	19.8
Medium	51	99.5	26.1
Large	360.5	206	54.1
Total	119.5	381	100
Hydroponic			
Small	18	1.5	1.9
Medium	59	13.5	17.2
Large	483	63.5	80.9
Total	345.0	78.5	100

[a] Small: 20 plants or less; Medium: 21–100 plants; Large 101 + plants

[b] Cases in which the number of plants was not specified were removed from the analysis ($N = 349$, or 174.5/year)

faced by both types of indoor growers (hydroponics and soil-based) should be underestimated.[1]

The seizure data set was useful in providing a distribution of sizes for the cultivation industry as a whole.[2] Similar to prevalence studies that distinguish between heavy and light drug users in order to account for large differences in drug use patterns (e.g. Everingham et al. 1995; Pudney et al. 2006), the estimation procedure that is developed in the current paper distinguishes between small non commercial sites (20 plants or less), small commercial sites (21–100 plants), and large commercial sites (101 + plants). As presented in Table 1, adding the three cultivation techniques creates nine types of cultivation sites. Descriptive seizure data show that size distribution differs by cultivation technique. Only a small percentage of sites operated for personal use are found for indoor and hydroponic sites, whereas more than a third of outdoor sites qualify as non commercial.[3] Another

[1] The SPVM is assumed to intervene on a similar number of indoor and hydroponic cases than the rest of the province. For example, a newspaper article reported that the SPVM discovered 28 hydroponic greenhouses in 1998 (Breton 2000), whereas our QPP data indicate that they discovered 31 sites for that same year. This underestimate of indoor and hydroponic seizures will be taken into account when analyzing the risks of detection later in the paper.

[2] Using data on seizures may not reflect the distribution of sizes for the industry as a whole but only those at risk of being detected, a convenient bias for an analysis concerned with providing estimates for this type of sample.

[3] The very low proportion of non commercial sites found in the sample is interesting. Qualitative studies like those of Weisheit (1992), or Hough et al. (2003) almost exclusively interviewed small-time growers which gave the impression that they represented the majority of growers. Conversely, by relying on police data, the current study probably overemphasizes larger cases, but nonetheless demonstrates that they are far from scant, at least in the region under study.

finding is that, as the level of sophistication of the technique increases, so does the median number of plants grown.[4] Overall, outdoor sites usually contain between 35 and 40 plants, the size increases to a little more than a 100 plants for indoor sites, and to nearly 350 plants for hydroponic ones.[5]

Fieldwork data

Information on the co-offending patterns for cultivation sites of different sizes was also needed to derive the prevalence of cultivation sites. Such data were retrieved from a convenience sample of 20 interviewed growers who were active in the Quebec industry between 1998 and 2005. I interviewed nine growers between 2004 and 2006. Growers were recruited in a variety of informal ways,[6] and interviews were conducted in cafés and pubs in Montreal and Quebec City. Information was gathered on many topics, including details on the dynamics of their career in cannabis cultivation, and a variety of issues touching the social and economic world of cannabis cultivation. Only information on key variables regarding co-offending patterns was analyzed for the purpose of this study.

I also obtained access to the written accounts of 17 interviews conducted by undergraduate students in a criminology class at Université de Montréal between 1998 and 2003. Students were asked by the professor to meet with a ''successful delinquent''. Eleven interviews were added to the sample because they contained precise information on both of the key parameters used in this study: the number of plants grown for a specific crop, and the number of co-offenders involved from start to finish. The total sample of 20 growers were 95% males, they had a mean age of 27 years, were involved on cultivation sites of 118 plants (mean), and described the cultivation patterns of 34 crops (10 outdoor, 13 indoor, and 11 hydroponics). Only crops for which growers reported different parameters (e.g. change in the number of plants, co-offenders involved, or cultivation technique) were added to the fieldwork data set. Compared to arrest data, the interviewed sample comprised more males and younger growers who were involved on smaller cultivation sites. However, the correlation between the number of plants grown and the number of co-offenders involved is very high ($r = 0.88$, $P < 0.001$) and the range of sizes found in the sample of interviewed growers is wide (from 1 to 1,800 plants grown). Thus, simple OLS regression models should provide valid estimates of the number of co-offenders necessary for the median sizes derived from seizure data.

[4] It is likely that these figures on the number of plants per cultivation site are inflated, because police typically treat all types of plants equally: plants of low quality, or baby plants, are counted even though only a variable amount of these will reach maturity. The inflation rate is unknown, but is not a major problem for the purpose of this study as it is likely to be constant for all types of cultivation sites. However, the inflated figures would be problematic for a different study that wanted to estimate the quantity of marijuana produced in the province. Such an estimate would also be inflated.

[5] The median is used because the distribution of sizes is highly skewed. The mean number of plants seized is 132, 372, and 816 plants for outdoor, indoor, and hydroponic sites, respectively.

[6] One respondent was referred by a colleague criminologist who was supervising him while he served the end of a federal sentence in a halfway house in Montreal after being found guilty of cannabis cultivation. Two other respondents were referred by a criminology student after a seminar I taught on cannabis cultivation. The six others were referred to me by mutual acquaintances after learning about the research.

Estimation model

I start by presenting the estimation model that will be used to estimate the prevalence of marijuana growers. I will proceed with the results derived from that first model before considering the second model developed in this study to estimate the prevalence of cultivation sites.

Zelterman's truncated Poisson estimator

Truncated Poisson methods such as Zelterman's estimator (Z) provide the necessary framework for estimating hidden populations of offenders. If data on known arrests and re-arrests follow the Poisson distribution specified by Z's model, the missing cell in the distribution should be estimated correctly, that is, the number of offenders with zero arrests. For data to follow a general Poisson distribution, a number of assumptions must be respected: (1) the population under study must be closed; (2) the population has to be homogenous; (3) the probability for an individual to be observed and re-observed must be held constant during the observation period (the independence assumption).

Such assumptions when using data on criminal populations may not be respected. The first and second assumptions pose obvious difficulties. Offenders tend to go in and out of offending at different periods of their lives; some are more active than others, and they may trigger different probabilities of arrest and re-arrest. Moreover, arrested offenders may modify their behaviour after an arrest, and police may also be tempted to over-target them following an arrest, leaving the third assumption unsatisfied.

Zelterman (1988) derived a truncated Poisson estimator designed to be robust to departures from these assumptions (see also Collins and Wilson 1990; Smit et al. 1997; 2002). It is given by

$$Z = N / (1 - e^{(-2n_2/n_1)}) \qquad (1)$$

where Z is the total population, N is the total number of individuals arrested with a marijuana cultivation charge, n_1 is the number of individuals arrested once, and n_2 is the number of individuals arrested twice in a given time period.

Zelterman's Poisson estimator has a number of attractive features for estimating criminal populations. First, it can minimize the impact of population heterogeneity in arrest risks by eliminating the minority of high-rate offenders with multiple arrests. In fact, Eq. 1 shows that only those offenders arrested once (n_1) or twice (n_2) are considered for establishing the arrest rate parameter. Zelterman (1988) and other researchers who derived similar models (Chao 1989), base their approach on the rationale that estimation models should be complex enough to be meaningful, but simple enough to contain only the parameters that are necessary, and close to the quantity to be estimated: "Observations that are close to the object of interest should, intuitively, have more bearing on it" (Zelterman 1988, p. 227). In other words, using information on those offenders who are not arrested very often should be more meaningful in assessing the prevalence of non arrested offenders. The trade-off is that Zelterman's estimator will generally provide less information, and more conservative estimates than more complex models that consider the full range of arrestees and their different arrest rates (e.g. an heterogenous Poisson model), or models that consider a series of covariates in fitting an estimation curve (e.g. a Poisson-based regression model). For example, compared to the 30,298 index offenders estimated by Greene and Stollmack's (1981) heterogenous Poisson model for D.C. in 1975, the Z model derives an estimate of 29,842 offenders (a 2% underestimate). Compared to the 62,722 illegal gun possession offenders estimated by van der Heijden et al.'s (2003) Poisson-based regression model, the Z model derives a 50,866 offender estimate (a 23% underestimate). The arrest risks derived from Z will increase accordingly, but the effects are usually not dramatic: in the latter example, the estimated risks increase from 4% to 5% of illegal gun owners arrested annually.

Another advantage of the model is it can be used on only one sample (as with arrest data), whereas other capture–recapture approaches require three or more samples to derive estimates. The use of multiple samples is warranted in many situations. For example, one interested in estimating the total population of drug users should not strictly consider treatment data (entry and re-entry into treatment), but also possibly arrest and hospital records (Hser 1993). Using only arrest data confines the interpretation to prevalence estimates of offenders "at risk of being arrested," which only concerns a minority of illegal drug users, but the majority of their suppliers (Bouchard and Tremblay 2005).

The Z estimator, however, assumes that the hidden population of interest is a "closed" population. The likelihood of severe departures from this assumption is minimized by the paper's analysis of re-arrest distributions at an aggregate level (arrests and re-arrests at the provincial level) rather than at a city or neighborhood level. This procedure does not account for the fact that some offenders may go in and out of the criminally active population, but it reduces the possibility of offenders being excluded from the sample simply because they moved to another city or neighborhood. There is also some indication from the literature that, in most cases, using closed population models on open populations is not a major sin. Kendall's (1999) simulations showed that animal prevalence estimates from closed population models are only minimally affected when movements in the population occur randomly, and when there is no sign of a massive emigration or immigration during the period under study. If the period under study is short enough, criminal population movements are unlikely to be swift and massive enough to have an impact on the prevalence estimates derived from closed population models such as Zelterman's.

In order to estimate yearly variations in populations of active offenders at risk of being arrested, the analysis used a moving average which, at all times, included three years. For example, to estimate the population of growers at risk of being arrested in 1998, the arrestee population from 1997 to 1999 was pooled. For the year 1999, the year 1997 was dropped and 2000 was added. The strategy of using a three-year unit of estimation has clear advantages. First, it gives growers a reasonable length of time to get re-arrested and to start another cultivation site. Most arrested and convicted growers in Canada are not sentenced to incarceration, but when they are (in less than 20% of cases), sentence duration is less than 6 months (Plecas et al. 2002). Second, capture–recapture methods require some minimal level of re-arrests to function, and using only one year would not generate enough re-arrests for the estimator to be used. Recidivism in marijuana cultivation is slower because it requires some level of organization. Especially for indoor ventures, it can take a few weeks to find a (new) cultivation site, to convince other interested co-offenders, or to gather the necessary start-up capital. This is indicated in the data by the higher proportion of re-arrested offenders for soil-based growing (3.1%) than for hydroponics cultivation (1.3%). The option of using more than three years was also considered. However, this would have violated other assumptions, basically that growers remain in the criminally active population for as long as four or five years, which would have exaggerated the average career length of non-recidivist offenders.

Table 2 Theoretical (T) and Observed (O) arrest distributions for a marijuana cultivation offense, and goodness-of-fit values for zelterman's estimator

# of arrests	1998		1999		2000		2001		2002	
Soil-based	T	O	T	O	T	O	T	O	T	O
1	2643.1	2641	3206.9	3206	3814.5	3814	4051.2	4051	4306.8	4303
2	55	55	70	70	93	93	105	105	116.1	116
3	0.8	3	1	1	1.5	2	1.8	2	2.1	6
4	0	0	0	1	0	0	0	0	0	0
X^2	1.33		1.00		0.13		0.02		2.54	
Hydroponic										
1	616	616	808	808	1081	1080	1245	1245	1219	1219
2	8	8	8	8	14	14	17	17	17	17
3+	0	0	0	0	0	0	0	0	0	0
X^2	0.00		0.00		0.00		0.00		0.00	

Notes: Neyman's X^2 is given by $X^2 = \sum_{j=1}^{k} \frac{(n_j - \hat{n}_j)^2}{n_j}$

Model evaluation

An important criterion in the choice of a model is that it provides a good fit to the data, that is, the distribution of arrests and re-arrests estimated by the model should resemble the observed distribution derived from the data. Table 2 presents the theoretical and observed distributions of soil-based and hydroponic growers arrested for the years 1997–2003.[7] Neyman's chi-square test was used to evaluate the fit.

Apparent from examining the distributions and the low or null chi-square values is that Zelterman's estimator provides a near perfect fit to the data. The estimator performs well with the data because the distributions analyzed have very few cases of three or more arrests, parameters that are not captured by the model (see Eq. 1 *supra*). The smaller the proportion of multiple arrests (3+), the better the fit. Although goodness-of-fit tests are not truly decisive criteria in the choice of a model (Coull and Agresti 1999), such a good performance supports the use of the Z estimator and other similar models (e.g. Chao 1989) in this particular case. It should also be noted that Zelterman's estimator has been shown to perform well as an estimator of hidden populations, even in circumstances where the model fit is weaker than what is the case in the present analysis (Bohning et al. 2004; Collins and Wilson 1990; Wilson and Collins 1992). Other criteria in model evaluation include an estimation of the intervals of confidence generated by the model. Those estimated in the present analysis (using Zelterman 1988) are narrow enough to be considered meaningful, especially for distributions with a larger proportion of re-arrests (such as the distributions for soil-based growers, see Table 2). The wider confidence intervals calculated for hydroponic growers illustrate the fact that capture–recapture estimates become more

[7] The theoretical distributions can easily be estimated by creating a spreadsheet similar to the Poisson distribution calculator available on Carnegie Mellon University Department of Biology's website: www.bio.cmu.edu/courses/03438/PBC97Poisson/PoissonCalc.xl. The arrest rate parameter necessary for such calculation must first be estimated by Eq. 1, i.e. by dividing the total number of arrests by Z, the estimated prevalence of growers.

volatile when used on distributions that depend on lower proportions of recaptures. On the other hand, Zelterman (1988) designed the estimator to be robust especially with this type of data (Choi and Comiskey 2003).

Results

Table 3 presents the estimated populations of growers at risk of being arrested between 1998 and 2002 for the two categories found in arrest data: soil-based growers (indoor and outdoor), and hydroponic growers. Prevalence estimates were derived using Eq. 1 for each arrest distributions presented in Table 3. The pooled Z estimates were also divided by three to produce an annual population of marijuana growers in Quebec that can be compared.

Based on the arrest and re-arrest distributions presented in Table 3, the model estimates that there were almost twice as many soil-based growers (28,102) as hydroponic growers (14,978) in 2002. Simplifying the logic of the model, these estimates are derived by combining two pieces of information: the total number of growers arrested (N in Eq. 1),

Table 3 Estimated populations of soil-based and hydroponic growers, Quebec, 1998–2002

	1998	1999	2000	2001	2002
Soil-based growers					
Z estimate[a]	66,159	76,717	82,126	82,307	84,305
C.I.[b]	(61,845–71,121)	(72,561–81,379)	(78,382–86,245)	(78,781–86,163)	(80,904–88,004)
Arrests (N)					
0[c]	63,460	73,439	78,217	78,149	79,880
1	2,641	3,206	3,814	4,051	4,303
2	55	70	93	105	116
3	3	1	2	2	6
4	0	1	0	0	0
Annual population at risk of arrest[d]	22,053	25,572	27,375	27,436	28,102
Hydroponic growers					
Z estimate[a]	24,337	41,617	42,825	46,845	44,935
C.I.[b]	(18,635–35,068)	(33,686–54,434)	(36,466–51,870)	(40,597–55,183)	(38,933–53,126)
Arrests (N)					
0[c]	23,713	40,801	41,730	45,583	43,699
1	616	808	1,081	1,245	1,219
2	8	8	14	17	17
3+	0	0	0	0	0
Annual population at risk of arrest[d]	8,112	13,872	14,275	15,615	14,978

[a] As estimated by Eq. 1, for three years (e.g. 1998 = 1997–1999)

[b] Confidence intervals, as estimated using Zelterman (1988: 228, Eq. 7)

[c] Z estimate—number of arrested offenders

[d] Z estimate/3, to reflect a moving average population for each year

and the proportion of offenders re-arrested for a specific offense ($\sim 2 * n_2/n_1$). For example, for the 2001–2003 period (or 2002 in Table 3), there were 3.6 times as many soil-based arrests as hydroponic arrests (4,553 vs. 1,553 total arrests), but also twice as many soil-based growers re-arrested (2.76% vs. 1.38% re-arrests). The model assumes that this lower proportion of hydroponic growers re-arrested translates into lower arrest risks for these growers as a whole. As a result, instead of assuming that there are 3.6 times as many soil-based growers as hydroponic growers, the model estimates that the difference is almost twice as small (1.9).

Adding the annual estimates for hydroponic and soil-based cultivation in Table 3, the Z estimates reveal that an annual average of 30,000–45,000 offenders were active and at risk of being arrested for a marijuana cultivation offense between 1998 and 2002 in Quebec. This estimate of the size of the industry is an interesting finding in itself. One can first appreciate the meaning of such an estimate through a comparison with the number of marijuana users in the province. The *2004 Canadian Addiction Survey* indicated that 15.8% of the Quebec population aged 15 and older had used marijuana in the year preceding the survey; this amounted to 990,531 estimated users. Assuming that all growers are at least occasional users, this number would imply that between 3% and 4.5% of self-reported past-year marijuana users would also be marijuana growers. Unfortunately, the Canadian survey does not ask respondents whether or not they grow marijuana, but the figures presented in this paper are comparable to findings reported elsewhere. For example, a survey conducted in New Zealand indicated that 3.4% of marijuana users interviewed had grown "most to all" the marijuana they consumed (Field and Casswell 1999). Another survey conducted in Amsterdam indicated that 17 out of 214 (8%) marijuana users were also growers at the time of the interview (Cohen and Kaal 2001).[8] The prevalence of marijuana growers in Quebec derived from capture-recapture analysis appears to be reasonably lower than the level found in an important producing region like Amsterdam, and interestingly similar to New Zealand—a country which also shows comparable prevalence rates of cannabis use.

Perhaps more informative is a comparison of these estimates with similar estimates of the prevalence of marijuana dealers in this region. Using the same model, Bouchard and Tremblay (2005) estimated that close to 45,000 offenders were at risk of being arrested for a marijuana dealing offense in 1998 in Quebec, making the marijuana dealing and cultivation trades roughly similar in size. This finding is important, because it offers a representation of market structure that is different from the pyramidal view that characterizes the distribution chain of most importation-driven illegal industries. A lengthy distribution chain that widens slowly down to consumers becomes less important here. One can hypothesize that the mere prevalence of growers makes it possible that most users can get supplies directly from growers, or they remain only one handshake away from access to a crop. A classical chain distribution probably remains to distribute the marijuana coming out of the largest cultivation sites. However, as far as size is concerned, these findings suggest that the cultivation industry is now a significant criminal opportunity for offenders in Quebec.

[8] The survey also included the cities of San Francisco and Bremen, Germany, but findings were either unclear, or the amount of users interviewed insufficient to reach any conclusions. For example, only one user out of 262 in San Francisco reported growing marijuana at the time of interview, but more than 79 said they had done so in their lifetime. In Bremen, 4% of respondents said they grew marijuana at the time of the interview, but the sample is simply too small ($N = 50$) to make any inference about the prevalence of growing among users in this city.

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The estimates presented in Table 3 also show that the prevalence of marijuana growers at risk of being arrested increased during the period under study: from 30,000 growers in 1998 to 45,000 in 2002. The rise is consistent with trends in drug use in Quebec. The *2004 Canadian Addiction Survey* indicated that the number of individuals who had consumed marijuana in the year preceding the survey increased by 23% in Quebec since 1998 (compare Daveluy et al. 2000, and Canadian Center for Substance Abuse 2004). The increasing trend is also consistent with government reports asserting that Canada is exporting increasingly larger amounts of marijuana to the United States in recent years (NDIC 2004). But perhaps more importantly, the growth almost exactly parallels the rise in the number of legal "grow shops" selling cultivation equipment and supplies to plant growers. The number of grow shops increased from 50 to 82 between 1998 and 2002 (Bouchard 2007), a 64% increase that compares to the 50% increase in the prevalence of marijuana growers illustrated in Table 3. It would take a few more years of observation to determine a real trend for the marijuana industry and to be able to interpret it properly, but the estimates suggest that the development of the industry may have reached a plateau in recent years, after a period of rapid growth. Incidentally, the prevalence of grow shops also reached a plateau after 2000 in Quebec (Bouchard 2007).

Criminal population estimates can be used as a relevant denominator to calculate a different type of arrest risk than what is typically presented in studies interested in these issues. Instead of considering "how many arrests for how many crimes" (Blumstein et al. 1986), criminal population estimates allow consideration of the following measure: how many arrests for how many offenders at risk? Such a measure is especially important for drug market crimes for which the total number of crimes (e.g. the total number of drug transactions conducted in a year) is not necessarily as meaningful a risk measure than for most predatory crimes (Bouchard and Tremblay 2005).

Table 4 presents the annual risks of being arrested for a cultivation offense according to the technique used by growers. Three observations stem from this analysis. First, the risks of being arrested for a cultivation offense are quite low (between 2 and 5%), at least compared to similarly derived risks for drug dealers (3–7%) in Quebec (Bouchard and Tremblay 2005). Despite the large increase in resources invested in marijuana eradication

Table 4 Annual prevalence of soil-based and hydroponic growers and the risks of being arrested for a marijuana cultivation offense, Quebec, 1998–2002

	1998	1999	2000	2001	2002
Soil-based					
Prevalence of growers at risk[a]	22,053	25,572	27,375	27,436	28,102
Number of arrests[b]	920	1118	1332	1422	1518
Annual risks of arrest (%)[c]	4.2	4.4	4.9	5.2	5.4
Hydroponic					
Prevalence of growers at risk[a]	8112	13,872	14,275	15,615	14,978
Number of arrests[b]	211	275	370	426	418
Annual risks of arrest (%)[c]	2.6	2.0	2.6	2.7	2.8

[a] Z estimate, from Table 3

[b] Mean number of arrests for three-year period (e.g. 1998 = mean number of arrests for 1997–1999)

[c] Number of arrests/prevalence of growers at risk

programs in Quebec, still very few growers are apprehended. Second, risks are more than twice as low for hydroponic growers (2–3%) compared to offenders involved in soil-based methods (4–5%).[9] This finding is surprising, because the police are not likely to know, before intervening on a site located indoors, which specific technique (soil-based or hydroponics) is used by the growers.[10] In addition, data on seizures indicate that hydroponic cultivation sites are, on average, four to five times as large as soil-based sites (Table 1). This finding suggests that hydroponic growers might be more successful at avoiding detection than other indoor growers. Given the average size of their cultivation sites (median of 350 plants), they certainly have more to lose than other types of growers, and are more likely to have the financial capital necessary to invest in protection devices.

Lastly, Table 4 illustrates the importance of analyzing the trends in arrest and re-arrest patterns, instead of just the absolute number of offenders arrested for a specific offense. The third and sixth rows of Table 4 present the number of arrests for soil-based and hydroponic cultivation, respectively. Both trends suggest that marijuana cultivation may have become more risky during that time period: The number of arrests for soil-based cultivation increased by 65% while the number of arrests for hydroponic cultivation almost doubled, from 211 to 418 arrests. However, the capture–recapture analysis suggests a very different picture. The risks for hydroponic growers remained mostly unchanged during that period, while the population of soil-based growers rose enough to absorb most of the parallel rise in arrests.

The prevalence of cultivation sites and the risks of detection

Risks of arrest for marijuana growers should be distinguished from risks of detection for cultivation sites. Estimating the risks of detection is important because losses for these offenders can be significant, especially for indoor and hydroponic cultivation sites. Furthermore, because a significant proportion of outdoor growers are never arrested, seizures often represent the only costs incurred by these offenders. What proportion of cultivation sites are detected by law enforcement?

The strategy used to estimate the number of cultivation sites begins by adjusting the prevalence estimates of soil-based growers (see Table 6, Appendix A). Adjustments are necessary for two reasons. First, the prevalence of cultivation is derived from the prevalence of growers "at risk of being arrested." Not all growers may be at risk of being arrested. For example, seizure data show that only 14% of outdoor cases lead to at least one arrest. As expected, the proportion is much higher for indoor (76%), and hydroponic cases (95%). Adjusting the prevalence of soil-based growers to take these cases into account, the estimates for soil-based growers increase from 28,102 to 39,733 in 2002 (Table 6, Appendix A). Second, arrest data do not distinguish between outdoor soil-based growers from those who grow in indoor settings. This distinction is important for an analysis of the risks of detection: outdoor sites are likely to be more vulnerable to detection than indoor cultivation sites located in private houses or apartments. Fortunately, seizure data make

[9] Note that the risks for soil-based growers remain higher overall, even when the adjustment procedure is taken into account (Table 4, Appendix A).

[10] Because very few outdoor soil-based growers are likely to be at risk given the low percentage of outdoor seizure that lead to an arrest (14%), the figures presented for soil-based cultivation mostly concern indoor growers.

that distinction. For example, it is estimated that among the 39,733 estimated soil-based growers for 2002, 37% are outdoor, and 63% are indoor growers (Table 6, Appendix A).

Prevalence estimates of marijuana cultivation sites can be derived from these adjusted populations of growers. The calculation could be labeled as a "division of labor" approach, as it uses information on the specific co-offending patterns of different types of cultivation sites, allowing for the possibility of economies of scale for large commercial sites. From Eq. 1 *supra* is derived a prevalence of cultivation sites, which is given by

$$S = \sum (Z_i/c_i)\lambda_{i,n} \quad (2)$$

where S is the annual number of cultivation sites at risk of detection, Z is the prevalence of growers of type i, c is the number of co-offenders working on a median size of type i, and λ represents the proportion of seizures for type i and of sizes n.

As illustrated in Table 5, prevalence estimates for nine types of cultivation sites can be derived from Eq. 2. The Z estimated prevalence of growers for 2002 were taken for the calculations (column 2). Median size (column 3) and the distribution of seizures according to size and type of cultivation site (column 5) were retrieved from seizure data (see also Table 1). The number of co-offenders for a given median size (column 4) has been estimated by linear regression analysis, using fieldwork data. Regressing the number of plants harvested by growers on the number of co-offenders involved in the cultivation site from start to finish provided a satisfactory and interesting measure for the purpose of the

Table 5 Annual prevalence and risks of detection by type of cultivation sites, Quebec, 2000–2001

Type of cultivation site	Prevalence of growers[a]	Median size (# of plants)	Co-off/med size[b]	Percent of Cases	Prevalence of cultivation sites[c]	Mean annual # of cases	Risk of detection
Outdoor							
Small	14,644	9	2.9	36.8%	1,858	358	19.3%
Medium	14,644	45	3.3	36.5%	1620	355	21.9%
Large	14,644	228.5	5.5	26.6%	708	259	36.6%
Indoor							
Small	25,089	7	3.0	19.8%	1,656	75.5	4.6%
Medium	25,089	51	3.4	26.1%	1,926	99.5	5.2%
Large	25,089	360.5	5.9	54.1%	2,301	206	9.0%
Hydroponic							
Small	14,978	18	3.1	1.9%	92	1.5	1.6%
Medium	14,978	59	3.4	17.2%	758	13.5	1.8%
Large	14,978	485	5.8	80.9%	2,089	63.5	3.0%
Total					13,008	1431.5[d]	11.0%

[a] Adjusted prevalence figures for outdoor and indoor growers for 2002 (from Table 6, Appendix A)

[b] As estimated through OLS regression, using fieldwork data. See footnote 11

[c] As estimated by Eq. 2

[d] The mean number of seizures for 2000–2001 is 1606. However, the number of plants was not specified in 10.8% of cases (or 174.5 per year). Adding these cases increase the risks of detection by 1.3%, or from 11.0% to 12.3%

current study.[11] All three cultivation techniques required a minimum of three co-offenders to set up even a small cultivation site, but the larger hydroponic sites benefited from economies of scale. Both large outdoor and hydroponic sites require the collaboration of 5–6 co-offenders, but hydroponic sites are more than twice as large (Table 5).

Columns 2–5 are used in the calculation of S (column 6). For example, to estimate the number of indoor sites of more than 100 plants, I divide 25,089 by 5.9 co-offenders for a median size of 360.5 plants, and then multiply by 0.54—the seizure rate for outdoor sites of more than 100 plants to obtain a prevalence of 2,301 of such cultivation sites. Overall, Table 5 reveals that the 54,711 estimated marijuana growers in 2002 were active in about 13,008 cultivation sites in Quebec (mean of 4.2 co-offenders per site). Whereas the prevalence of outdoor and hydroponic growers was found to be similar (column 2), the smaller size of outdoor sites increases their overall prevalence compared to hydroponic sites (4,172 vs. 2,925). However, the larger size and higher productivity of hydroponic sites gives them a larger share of the total marijuana production in the industry.

Risks of detection were calculated for the different types of cultivation sites (Table 5, last column) by dividing the mean annual number of seizures (column 7) by the estimated prevalence of cultivation sites (column 6). Because the majority of cultivation cases start from a seizure but not all cases lead to an arrest, risks of detection were expected to be larger than the arrest risks calculated earlier (Table 4). Table 5 shows that the mean risks of detection for outdoor and indoor sites were 19–37% and 5–9% respectively, compared to risks of arrest of the order of 4–5% for growers involved in such sites. More similar risks of arrest and risks of detection were found in the hydroponic industry, perhaps a consequence of the high rates of arrest following a seizure (95%).

These findings confirmed a general impression from drug market commentators that outdoor sites are more vulnerable to detection than indoor greenhouses.[12] Interestingly, the magnitude of the estimated risks of detection is in line with other research on "rates of interception" at the import or production levels. Using some of the best data and estimation procedures available, Rhodes et al. (2000) suggested that US authorities were seizing between 10 and 15% of heroin, and 20–25% of cocaine entering the US. Wilkins et al. (2002b) recently estimated that risks of detection for outdoor marijuana production sites vary between 26 and 32% in New Zealand, acknowledging that these rates appear higher than those being recorded overseas. Based on the analysis undertaken for this paper, it is estimated that between 19 and 37% of outdoor cultivation sites are eventually detected.

Contrary to the aforementioned studies, however, the present analysis offers the advantage of estimating risks of detection according to the size of the cultivation site. By simultaneously presenting data on the size of a criminal enterprise and on the risks of detection, the proposition that risks increase with the size of illegal ventures can be tested. The relationship between risks and size has often been explored in different contexts (most notably in Reuter 1983, 1985), yet, scarcely measured empirically. In the case of marijuana cultivation, one could hypothesize that larger sites are more vulnerable to seizures because of the increased number of co-offenders who participate (the group hazard hypothesis), because of the heightened risk of system failures for large indoor sites (e.g. floods, fire),

[11] I used a simple linear regression model of the form $C = a + b*p$, where C is the number of co-offenders per site and p is the number of plants grown per site. The regression coeffients are presented as following: for outdoor sites ($n = 10$): $C = 2.805 + 0.0116*p$; for indoor sites ($n = 13$): $C = 2.935 + 0.0082*p$; for hydroponic sites ($n = 11$): $C = 2.981 + 0.0057*p$.

[12] The finding holds even when increasing the number of seizure cases by a factor of two—to compensate for the absence of most cases from Montreal.

outdoor settings. Conversely, outdoor cultivation sites are still found in large proportions, partly because they are typically smaller in size. It also appears that soil-based methods are not disappearing to the benefit of hydroponics, despite the enhanced productivity associated with the more sophisticated techniques.

An interesting spin-off provided by method-specific population estimates is the possibility of comparing the aggregate level of risks faced during the course of one year by marijuana growers involved in different cultivation techniques. Method-specific comparisons indicate certain inequalities in the distribution of risks. Risks of arrest are lowest for hydroponic growers compared to growers involved in soil-based methods. This finding persists when considering the risks of detection. As expected, risks of detection do increase with size, but only within a particular technique. Hydroponic facilities, even the largest ones, have a 2–3% risk of detection, compared to risks of 5–9% and 19–37% for indoor and outdoor sites respectively. Hydroponic growers appear to be better than other growers at protecting themselves and their cultivation sites from police detection.

These findings are subject to the validity of the prevalence estimates derived from Zelterman's (1988) truncated Poisson estimator. These estimates are based on a number of assumptions that are likely to be violated and the impact of the violations is not always easy to assess. A first unresolved issue concerns the independence assumption, which asserts that the occurrence of one event (e.g. an arrest) will have no incidence on the probability of subsequent events. In other words, the independence assumption excludes the possibility of behavioral change that could reduce the risks for a particular offender (e.g. through a deterrent effect) or increase them (e.g. the police targeting past arrested offenders). Both scenarios are possible but none are expected to be important enough to have an impact on the prevalence estimates. Drug offenders typically show very high rates of recidivism following incarceration or probation (Spohn and Holleran 2002), but such rates could not be calculated for the purpose of the current study. With regard to police targeting previously arrested offenders, it should be noted that only one offender was re-arrested more than three times during a seven-year span. Another issue with the independence assumption is that information on the arrest of one offender should not be viewed as providing information on the arrest of another offender. However, arrest data show that a significant proportion of growers are arrested with at least one other co-offender. The violation of this assumption is almost inevitable when using arrest data, but I am not aware of any study that tried to assess its effect on the population estimates. The effects of violating this particular assumption when estimating criminal populations should be assessed in future research.

Second, the study was designed to limit departures from the closed population assumption (no entries and exits during the capture–recapture experiment) by concentrating on a large geographical area (Quebec) and on a reasonably short time frame (three years), given the average career length of marijuana growers and the mean sentence meted out for those who are convicted. Open population models have the disadvantages of being much more complex and data intensive than closed population models, and the results are not always satisfactory (e.g. the Jolly-Seber model in Haer 1993; Brecht and Wickens 1993). However, these models offer a more realistic representation of the dynamics both in and out of criminal careers, and perhaps more precise estimates of the size of criminal populations. A possible hypothesis is that a Markov chain model could better depict the patterns in and out of outdoor marijuana cultivation—a seasonal criminal offense with high probabilities of arrest between August and October, and much lower the remainder of the year.

Finally, the homogeneity assumption (the population is homogenous with regard to arrest probabilities) may not be a major issue in this study. First, Zelterman's truncated Poisson model assumes that the capture probabilities of those offenders most rarely arrested follow a distinct pattern that should be estimated separately. Second, analyzing subgroups of growers who were homogenous relative to the cultivation technique that they used (soil-based versus hydroponic) also reduces heterogeneity. However, the distribution of risks within these populations may still vary widely. Although variations in the level of risks within a group may not constitute a violation of the Poisson distribution if risks are non zero (van der Heijden et al. 2003), researchers should pay attention to the distribution of risks—especially relative to the different roles assumed by offenders. An aggregate measure of risks like the one estimated in this study is useful for uncovering important macro level patterns, for example, that hydroponic growers almost completely avoid police detection compared to other types of growers. But one wonders whether or not a 5% risk level is meaningful for an important proportion of soil-based growers, or whether risks are more lopsidedly distributed, with low-level employees receiving the bulk of police attention.

One of the main findings of this study is that most hydroponic growers may receive very important financial incentives from their activities (given the size of the average cultivation site, their higher productivity rates, and the higher prices at which they can sell their product[14]) while systematically avoiding police detection. Hydroponic growers' dual advantage (low risks, high gains) over others may have important implications for the future developments of the marijuana industry. The success of hydroponics as a criminal innovation might induce other growers or would-be growers (including offenders involved in other crimes) to adopt this particular technique. The higher the prevalence of hydroponic cultivation sites, the more efficient offenders are, and the higher the organizational capacity of the marijuana industry. If detection of hydroponic sites continues to pose difficulties to police agencies, an increase in the prevalence of hydroponic growers will make the bulk of arrests continue to fall on the most vulnerable and less organized outdoor cultivation sites, further augmenting inequalities in the distribution of risks in the marijuana cultivation industry.

Whether or not the hydroponic technique "catches on" and continues to diffuse and be adopted by an increasing number of offenders does not strictly depend, however, on a cost/benefit analysis. Weisheit (1991, 1992) and Hough et al. (2003) demonstrated that marijuana cultivation, for a large number of growers, is not just about money but also about the "love of the plant." Many growers are part of what may be described as a marijuana subculture, cultivating marijuana for "intangible rewards", but their market significance is likely to be minor in terms of the total amount of marijuana produced. Perhaps more decisive at the macro level, hydroponic cultivation implies relatively large sizes to be advantageous. Offenders face limited opportunities for marijuana cultivation in indoor settings, and large-scale marijuana cultivation requires the common pooling of more co-offenders: first to produce, supervise, and run the installations, but also to distribute very large quantities of marijuana to consumers. The fact that outdoor cultivation provides new adopters with a smoother entry into the trade, along with the possible influence of demand-

14 Hydroponically produced marijuana is typically stronger in the drug's psychoactive content (Tetrahydrocannabinol, or THC) than soil-produced herb. Interviewed growers report that it is also sold at higher prices, and hydroponic growers can cultivate more crops per year than with any other method.

related factors (low prices, taste?), has probably prevented a faster or more significant shift to hydroponic cultivation in recent years.

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Appendix A

Adjusting the population estimates

An important difference between the seizure and the arrest data set is that the latter does not distinguish between outdoor and indoor soil-based growers. The distinction is important, especially for assessing the differential risks of detection. The procedure starts by establishing the proportion of soil-based growers involved in outdoor and indoor settings. Seizure data for 2000–2001 show that 68% of soil-based seizures are made on outdoor sites (2,075 total cases out of 3,051). Because 13.9% of outdoor seizures lead to arrest, it is estimated that 288 outdoor growers were arrested in 2000–2001 (assuming one arrested offender per case). A similar calculation for indoor growers gives 742 offenders, for a total of 1,030 soil-based growers arrested, 28% of which (288) are estimated to be outdoor growers. Because the number of offenders arrested per case does not vary by type of method or location (1.3 offenders per case), it is expected that 28% of the annual population of soil-based growers will be involved in outdoor production, and the remaining 72% are indoor growers.

A second adjustment was incorporated into the figures presented in Table 6. Capture-recapture estimates are valid models to estimate populations at risks of being arrested; these models are not designed to capture segments of a population that are shielded from arrest, if they exist. Although mathematically, every active offender has at least a small probability of being arrested (Greene and Stollmack 1981), data on seizures reveal that the majority of outdoor cultivation cases never lead to an arrest. In 2000–2001, 13.9% of outdoor seizures led to an arrest, whereas 76.3% of indoor (soil-based) and 95% of hydroponic seizure cases led to at least one arrest. Thus, prevalence estimates were adjusted to reflect the percentage of offenders affected by a seizure but never arrested, by type of technique (an inflation rate of 86.1% (or 100–13.9%) for outdoor cases, 24% for indoor ones). This adjustment is unnecessary for hydroponic growers, because almost all seizures involve at least one offender arrested. This second adjustment increased the prevalence of soil-based growers by an average of 10,000 growers per year.

Table 6 Adjusted populations of indoor and outdoor soil-based growers, 1998–2002

Type of soil-based grower	1998	1999	2000	2001	2002
Outdoor	11,492	13,325	14,265	14,296	14,644
Indoor	19,689	22,831	24,440	24,495	25,089

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Appendix N: Easton (2004) Marijuana Growth in British Columbia

PUBLIC POLICY SOURCES

Number 74

Marijuana Growth in British Columbia

by Stephen T. Easton

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Executive Summary

The cultivation and production of marijuana in British Columbia highlights the problems inherent in the enforcement of laws that are generally ignored by broad sectors of the populace. Some 7.5 percent of all Canadians report they use marijuana currently, and over their lifetimes, 23 percent report themselves as having used marijuana at least once.

This paper raises several issues that have the cumulative effect of suggesting that in the long term, the prohibition on marijuana cannot be sustained with the present technology of production and enforcement. To anyone with even a passing acquaintance with modern history, it is apparent that we are reliving the experience of alcohol prohibition of the early years of the last century.

In Canada, and more specifically British Columbia today, as with alcohol nearly a century ago, marijuana is too easily produced and exported to be controlled with the tools available to law enforcement in a free society. The return on investment is sufficiently great so that for each marijuana growing operation demolished, another takes its place.

For a modest marijuana growing operation of 100 plants, harvest revenue is from 13 kilograms of marijuana sold in pound blocks out the back door valued at $2,600 per pound. This amounts to slightly less than $20,000 per harvest. With four harvests per year, gross revenue is nearly $80,000. A conservatively high estimate of production cost is about $25,000. The return on invested money is potentially high: around 55 percent.

The underlying characterization of the marijuana grow operation is that it functions as a profit-maximizing activity in which the values of output and costs yield a market equilibrium rate of return. Such an assumption permits an estimate of the total number of grow-ops. The range of estimates depends upon the value of the crop, the costs of production, the risk-adjusted rate of return to other small businesses, and the likelihood of discovery by the police. For the year 2000, the estimated number of "grow-ops" in British Columbia may be as high as 17,500. Combined with domestic consumption, numbers of this magnitude suggest that exports from British Columbia are worth nearly $2 billion.

Why is it that indoor marijuana cultivation and consumption appear to take place more openly in BC than elsewhere in Canada? The most striking difference between BC and the rest of Canada lies in the rate at which offences are settled by charging the offender (or "cleared"). Only 13 percent of possession offences in BC are cleared by charge. Elsewhere in Canada over 60 percent of possession offences are cleared by charge. In addition, the penalties for conviction appear to be low.

In a sample of Vancouver marijuana growing operations "busted" by the police, most of those who were convicted received no jail time: 55 percent. Five more percent were sentenced to a single day or less and another 8 percent received sentences of between one day and 31 days, while still another 8 percent received 60 days. Some 11 percent were sentenced to 90 days. Of those who are repeat offenders, half are reconvicted within the year. Of the 35 percent who were fined, the average fine amounted to less than $1,200: a small amount considering the size of most marijuana operations. While police resources are spent to destroy nearly 3,000 marijuana growing operations a year, the consequences are relatively small for those convicted.

Current public policy proposals emphasize decriminalization. Suppose, however, that marijuana were treated like any other product and were to be sold at retail cigarette value rather than in bulk. At current prices, a marijuana cigarette costs about $1.50 to produce, and sells for around $8.60. Since the consumer currently is willing to pay $8.60, imagine a tax on marijuana cigarettes equal to the difference between the local production cost and the street price. This would transfer the revenue from the current producers and middlemen, many of whom are associated with organized crime, to the government. Crudely, government would have revenue of about $7 per cigarette. Using conservative assumptions about Canadian consumption, this comes to revenue of over $2 billion, and should marijuana be taxed on the same basis for export (leaving aside obvious problems of international diplomacy with the United States), additional revenue could be generated. Further, policing assets currently involved in enforcing marijuana-related statutes could be deployed elsewhere.

What the analysis reveals is how widespread marijuana use is in Canada and how extensive production is in British Columbia. As a consequence, the broader social question becomes less about whether we approve or disapprove of local production, but rather who shall enjoy the spoils. As it stands now, growers and distributors pay some of the costs and reap all of the benefits of the multi-billion dollar marijuana industry, while the non-marijuana-smoking taxpayer sees only costs.

Marijuana Growth in British Columbia

The cultivation and production of marijuana in British Columbia highlights the problems inherent in the enforcement of laws that are generally ignored by broad sectors of the populace.[1] Some 7.5 percent of all Canadians report they use marijuana currently (or at least have done so during the past year). Of those aged 15 years and older, about 23 percent of the Canadian population report that they have used marijuana at least once in their life.[2] By province there are variations in recent marijuana use with British Columbia the highest at 11 percent, and Newfoundland and Ontario the lowest at 3.8 percent and 5.1 percent respectively. There is variation in use by age and sex, with younger people more likely to have used the drug than older people[3] with males using at twice the rate of females.

This paper raises several issues that have the cumulative effect of suggesting that in the long term, the prohibition of marijuana cannot be sustained with the present technology of production and enforcement. To anyone with even a passing acquaintance with modern history, it is apparent that we are reliving the experience of alcohol prohibition of the early years of the last century.[4] In that sorry episode, on both sides of the Canada-US border the widespread demand for prohibited alcohol led to the rapid growth of criminal enterprises that expanded to produce the product that the general population desired.[5] As a testament to the enduring significance of the period, recall that even today we cheer for Eliot Ness as he smashes the alcohol making stills of organized crime in endless television reruns of *The Untouchables*. Ironically, we may now sip a cocktail as we do so.

In Canada, and more specifically in British Columbia today, as with alcohol nearly a century ago, marijuana is too easily produced and exported to be controlled with the tools available to law enforcement in a free society. The return on investment is sufficiently great that for each marijuana growing operation demolished, another will take its place.

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2 (Single *et al.*, 1999.) Contrast these figures with lifetime use of 8.1 percent for cocaine and 10.4 percent for LSD, speed, or heroin. On the legal side, 72 percent of the Canadian population has used alcohol in the past year, and 27 percent identify themselves currently as tobacco smokers.

3 Among those 15 to 19 years old, about 25 percent have used in the past year (Single *et al.*, table 5.3). Although it is not in the survey data, it may very well be that the younger set—aged 9 and up, should actually be queried as well. Data from grade schools suggest that use of marijuana in the past year in grade 7 is typically around 10 percent or below. The percentage swells to around 30 percent or higher by grade 9 (*New Brunswick Student Drug Use Survey 2002 Highlights Report; Nova Scotia Student Drug Use 2002 Highlights Report; Prince Edward Island Student Drug Survey 2002 Highlights Report*). Data from other provinces are consistent with these figures.

4 See, for example, Mark Thornton (1991), "Alcohol Prohibition was a Failure," *Cato Policy Analysis* No. 157 (January).

5 See, for example, Warburton (1932, chapter IX) or Thornton.

Although there are a host of important criminological, social, psychological, and economic issues associated with marijuana, this paper is primarily a framework that develops a series of "facts" and characterizations of the marijuana industry in British Columbia that can be revisited, revised, and challenged to make a sensible policy debate possible.[6] The first two sections of the paper organize the discussion using the economist's model of demand and supply with an emphasis on the latter. Subsequent sections include a methodology and estimate of the number of marijuana growing operations ("grow-ops" as they are popularly known) in British Columbia, some discussion of why British Columbia appears to be a significant location for marijuana production, and some thoughts about the transformation of currently illegal returns into tax revenue were marijuana to be made legal.

Canadian Marijuana Consumption

Marijuana consumption is difficult to measure. Although there are plenty of data about marijuana *use* in Canada, very little is quantitatively oriented. To say that someone "uses" once or twice a week is not very specific about the *quantities* they are likely to use. Reuter suggests that a "very heavy user of marijuana consumes about 3 marijuana cigarettes per day" (1996, p.7).[7] In Australia, usage has been measured in the Australian Institute for Health and Welfare *1998 National Drug Strategy Household Survey*.[8] More Australians appeared to have tried marijuana (39 percent compared to 23 percent of Canadians), and more Australians have used marijuana "recently" (18 percent compared to 7.5 percent in Canada).

The average marijuana cigarette is 0.4 to 1.0 grams in weight (Adams and Martin, 1997). [9]For those who still think in Imperial units, there are about 28.35 grams in an ounce or about 453.6 grams in a pound. There are, of course, 1,000 grams in a kilogram. Consequently, even if marijuana use is measured in number of cigarettes, quantity is still difficult to assess. Loosely, 15 grams of marijuana generates between 15 and 30 cigarettes according to taste. I have found no correction for the strength of the active ingredients

6 I do not discuss the Canadian federal government initiatives to decriminalize small amounts of marijuana. Such a proposal deserves a separate and specific response.

7 On the other hand, asking around locally suggests that this is high for British Columbia leaf. Anecdotally, a heavy user is said to use one cigarette per day.

8 Digital document available at *http://www.aihw.gov.au/publications/health/ndshs98d/*. Although these data have more information about frequency of consumption, quantity must still be imputed.

9 Others find slightly lower values at roughly 0.39 grams per cigarette (W. Rhodes *et al.*, 1995, *What America's Users Spend on Illegal Drugs, 1988-93*, Washington, D.C.: Office of National Drug Control Policy, p.20, cited in Reuter, 1996.) In contrast, commercial cigarettes weigh-in at 0.77 grams, a weight that appears to have stabilized since 1988. Prior to 1988, the weight of a cigarette had fallen from over 1.6 grams in the early 1950s to about 0.77 today (*http://www.ncth.ca/NCTHweb.nsf/0/ac4f6b07bdef1f9385256b6006e43b/$FILE/gdb6s-weight.pdf*).

on the "weight" of the cigarette. Some people report that they consume as many as 60 cigarettes per day, but they are obviously exceptional.

Some limits on the size of the *internal* market for marijuana

If roughly 7.4 percent of the Canadian population currently uses marijuana, then with 25 million Canadians aged 15 or over this implies about 1.87 million users. Table 1 puts this consumption into some kind of numerical perspective.[10] The first column identifies the number of users based on estimates of usage described in Single *et al.* (1999, Table 5.1) The second column gives an estimate in metric tons of internal Canadian marijuana consumption. The third column multiplies this by price to illustrate the size of the Canadian (consumption) market. This of course does not include exports. The final column details the expenditure by Canadians on (legal) tobacco for the past few years to illustrate the scale of the internal market.

How large is the industry? Expenditures on illegal marijuana in Canada are roughly the same order of magnitude as those on legal tobacco products. Substantial though these numbers may be, however, they are not the central issue. Even as the Government of Canada apparently plans to reduce the penalty for consumption, most attention focuses on production for which the external market in the United States is simultaneously an economic goldmine and a political landmine. As the evidence will show, it is obvious that much of the British Columbia marijuana crop is grown for export.

Table 1: Estimates of the Internal Canadian Market for Marijuana, 1988-2000

Year	Current users (millions)	Total internal consumption* (thousands of kilograms)	Annual expenditure on marijuana* (billions of dollars)	Annual expenditure on tobacco (billions of dollars)
1988	1.38	111.0	1.4	
1990	1.10	92.1	1.5	
1991	1.11	87.9	1.5	
1992	1.13	92.2	1.6	
1993	0.96	81.1	1.2	
1994	1.71	152.1	2.0	
1995	1.73	154.1	1.7	
1996	1.75	156.1	1.7	
1997	1.78	158.2	1.7	2.5
1998	1.80	160.1	1.9	2.5
1999	1.82	162.0	1.7	2.4
2000	1.84	164.1	1.8	2.3

*Table 1A provides upper and lower estimates.
Sources: See Appendix Table 1A.

10 This table is derived from Appendix table 1A, which details the sources and methods of construction. Table 1 uses the "low" estimates from table 1A.

Producing Marijuana in British Columbia

There is very little hard information about the actual number of marijuana growing operations ("grow-ops") in British Columbia. From the pattern of police enforcement we believe that the numbers have been increasing, but the actual scale of marijuana growing is difficult to know with assurance—for obvious reasons. From 1997 to 2000, Plecas *et al.* report that the number of grow-ops discovered and dismantled, or "busted" in the usual terminology, more than doubled: from 1,251 to 2,808. This issue is addressed below in the section titled "How Many Grow-ops are Out There?"

There are several ways to produce marijuana. I will discuss the outcomes of indoor supply, which is the most relevant to an urban setting and the current data set. Nearly 80 percent of all grow-ops discovered by police are indoor operations, although this reflects policing costs as well as the true distribution of grow-ops. Further, there are likely to be plenty of individual marijuana grow operations of a few plants that are not likely candidates to be busted and are consequently are not included in the statistics. Before turning to the production side of the marijuana industry, however, there is the matter of price that permeates any discussion of the business. The next section develops a characterization of the relationship between price and quantity that is used throughout the rest of the analysis. This is important because evaluating marijuana quantities sold at per pound prices of production may lead to different interpretations of size and significance of the industry than by evaluating marijuana sales at the more expensive "per cigarette" level of consumption.

The price of the product

To give some idea of the value of marijuana (Appendix A discusses the estimates in detail), table 2 uses estimated values computed from cross-Canada data gathered by the RCMP from 1995 to 1999. Aggregating these data and estimating a relationship for British Columbia gives a sense of the values appropriate for different quantities of the drug.[11]

Table 2: Retail Purchase Prices by Quantity of Purchase

Unit in which purchased	Year 2000 Canadian $ unit price	Gram weight of purchase	Price per gram of the purchase
0.5 gram	8.6	0.50	17.16
1 gram	15.9	1.00	15.93
1 ounce	254.5	28.35	8.98
1 pound	2,613.0	453.60	5.76
1 kilogram	5,077.0	1000.00	5.08

The underlying estimation appears as equation 2 in Appendix A.

11 Not all units were actually purchased or reported in the raw data. For example, the kilogram price is an extrapolation of the estimated power function that relates price to quantity. All the other quantities were part of the data set.

The table's first column reports the unit of purchase. The second column reports the average price of the purchase of that unit. The third column indicates the number of grams in the purchase bundle in order to put the purchases into a common unit. The final column reports the implicit price per gram at the different quantities. As is expected, larger quantities are cheaper on a per gram basis.[12]

Growth cycle and "bud" size

Outdoor crops mature once a year. Each indoor crop takes between 6 weeks and 4 months to mature.[13] To err on the side of caution, we will use a period that gives four harvests per year.

At harvest each plant produces one "bud" which is the structure that produces about 100 grams of usable marijuana. This, in turn, yields a dry weight of roughly 33 grams.[14] Although they may not be a representative sample, data from Vancouver police drug busts suggest that in 1998 a bud weighed about 3.3 ounces (100 grams). In 1999 the average bud had increased to 4.3 ounces (122 grams). Most estimates (Plecas *et al.*, for example) take 100 grams as the relevant average. This assumption will also be made in what follows.

Potency

One frequently uttered sentiment is that British Columbia grown marijuana is on the stronger end of the spectrum. This may be true, but it is tricky to document systematically. Data collected by the RCMP tend to suggest that the potency, the THC content, has remained roughly constant over the 1995 to 1999 period. Nationally, there was no obvious increase in the measured quality of marijuana acquired by the police from various activities: busts, buys, and the like. Within British Columbia, although the mean THC content has increased over the same period, that increase is not statistically significant.[15] Consequently, although it is possible that there has been an increase in the THC content (if popular reports are to be believed), it remains to be observed systematically, though the raw numbers are not inconsistent with an increase in the late 1990s.

The house

The marijuana producer needs an establishment to house a grow-op. Typically, grow-ops have been found in rented houses. A house typically rents for about $18,000 a year, though there is evidence that increasing the scale of production demands alternatives.[16] Grow-ops arise (in part) because they have a very quick time to market compared to natural marijuana crops that have an annual cycle.[17]

The equipment necessary to run a grow-op includes supplies, lights, fans, seeds, and miscellaneous other materials. For a 100-plant operation,

12 For example, Caulkins (1994) finds a similar relationship for cocaine prices and quantities in the United States.

13 A relatively new phenomenon is that grow-ops are being found with "continuous cycle" harvesting. That is, there is a "circle" of plants with one at each stage in the productions process. Such a model takes more hands-on work, since one task or another has to be performed more frequently, but if the grow-op is busted by competitors, then there is much less market-ready product available. A clear trade-off is being made.

14 In addition, there are often several smaller buds, but I have not seen estimates of how many or how large they are.

15 Based on 2,089 BC observations, the THC (delta-9-tetrahydrocannabinol) content from 1995-1999 was 6.5, 6.9, 6.6, 7.1 and 7.4 percent (Laids, 1999).

this amounts to about $10,000.[18] The electricity costs about $2,500 per year. Many growers gladly pay for it. Others fear that the hydro company will notice the extensive residential use of electricity and might investigate.[19] Still others simply steal the electricity.

Similarly, the grower cannot set up a generator in the back yard or on a balcony. It will make a conspicuous noise and will alert thieves who would help themselves to the maturing buds, an activity known as "grow-rips." Obviously, there is no public recourse if you, as a grower, are burglarized. Nor can you carry theft insurance for the valuable crop. This may also help to explain the boom in "guard" dogs in some parts of British Columbia's Lower Mainland as well as protection provided by organized crime for selected operations (Howell, 2002).

Ignoring electricity costs, table 3 reports that the total material cost of the operation is about $28,000. Obviously what is missing is the labour cost. At a minimum wage of $8 per hour over a 24-hour day to provide for constant security, the cost of labour could add another $70,000 to expenses. On the one hand, unlike the standard minimum wage paid and received, this is tax "free," and even the most intensively farmed grow-op does not really need 24 hour care all the time. Consequently, this is a *very* high estimate of labour costs, and means that we will tend to understate the profitability of grow-ops. On the other hand, there is always the possibility of violence associated with grow-ops, which adds a premium to the usual market wage. For obvious reasons it is difficult to document labour usage and remuneration patterns systematically.[20]

How much does such an operation produce?

Although most estimates of production are speculative or designed to serve a particular purpose, Plecas *et al.* (p. 35) find that the average number of plants discovered in all marijuana grow-op busts around the province has been on the increase. Across British Columbia from 1997 to 2000 the average number of plants seized rose from 140 to

16 Recent busts reported in Vancouver newspapers suggest that new houses worth $300,000 to $400,000 are being purchased and used for a year or so for such purposes. Large-scale production at greenhouse operations in more rural settings has also been found recently. This suggests that the scale of grow-ops is increasing and is not inconsistent with observations by Plecas *et al.*

17 A quick introduction to marijuana grow operations is available to anyone who wishes to peruse the Internet. The detail and apparent sophistication of the technology is voluminous. The police have provided tips for spotting grow operations: *http://www.city.richmond.bc.ca/emergency/police/grow_operations.htm*. There is information on the types of lights and programs necessary to maximize indoor yield by following the links at sites such as: *http://www.cannabislink.ca*; or *http://www.cannabisnews.com*. Easier yet, try typing something like "marijuana growing" into a search engine.

18 This is typical in the sense that even though the average size is higher than 100 plants per grow-op, most operations still remain small, and the high average is due to some really large and spectacular busts of thousands of plants. There are relatively few of these in the data. As a result, although I call this typical, it is a statement about most likely to be observed rather than mean number of plants. The average number of plants found in grow-ops is rising.

19 Interestingly, there is irritation among some in law enforcement that the electricity supplier is not active in identifying likely grow-ops unless they fail to pay their bills. If they fail to pay, or are found bypassing the meter, then the electricity company expects prompt action by the police since it is a theft in progress.

20 Sharecropping (in which the financer and the grower split the crop) also is known. Some informal reports to the author suggest a 50-50 split is common.

Table 3: A Calculation of Vancouver Grow-ops

Revenue	Numbers	Comment
Number of plants	100	Near both mean and median in 161 busts VPD* busts from 1994-1999
Number of seasons	4	From 6 to 12 weeks
Total number of buds produced during one year	4 x 100 = 400	Each bud is roughly 100 grams
Total weight in kilograms	13.3	(400 x 100) x ⅓ to account for dry weight
Price per pound (bulk)	$2,600	See table 2 (2.2 pounds per kilo)
Annual value of sales	$76,000	This is bulk (rounded)
Costs	**Numbers**	**Comment**
House rent	$18,000	Assumes full year occupancy
Supplies	$4,000	Fans, lights, containers, seeds, etc.
Wages (implicit or explicit)	$2,000	Care and clipping of plants
Electricity**	$2,500	Could be less if operator steals power
Operating Cost	$24,500	($1,500 per pound)
Share to operator	$38,000	50% of final product
Net revenue to investor*	$13,600	50% of revenue less operating cost
Return on a dollar of cost	55%	(All figures rounded)

*Source: Wickstead (2002) provides data about the size distribution of busts and the cost of supplies. House rents are a casual average from local newspapers. Plecas et al. provide estimates of the size of buds.
**Electricity at 0.57 cents per kWh implies an annual cost of $2,500 for lighting this operation. More generally this amounts to roughly $8.50 per plant.

180. There are apparently more operations, and an apparent increase in size of these operations.

A rough calculation of a marijuana grow operation

To get a sense of the numbers for a typical operation, assume a grow-op has 100 plants. This puts it in the "modest size for commercial use" category. Harvest revenue comes from 13.3 kilograms of marijuana sold in pound blocks out the back door at $2,600 per pound.[21] This amounts to slightly more than $19,000 per harvest. Since there are four harvests per year (on the conservative side), gross revenue is about $76,000. Even if costs are about $24,500, and the final sales are split equally with the operator, the net rate of return on invested money is potentially very high. The 100-plant grow-op makes around 55 percent return for a year's worth of activity using the most conservative assumptions.

But the rate of return is not *really* 55 percent. There is the chance that you will be busted–either by your colleagues on the wrong side of the law, or by the police. If 10 percent of grow operations were busted by police, competitors, or thieves, then the expected annual rate of return is about 40 percent.[22] This is still a fine rate of return if you can get it, but there are clearly risks in the busi-

21 This may be a little high currently, but see table 2. In discussing this figure with British Columbians who claim to know, they suggested that they were not able to get more than $1,900 per pound. This is casual empiricism and serves to alert the reader to the gross uncertainties of any estimates. Consequently, in estimating the number of marijuana grow operations (below), it is appropriate to use a wide range of assumptions.

ness that are not about business. Interestingly, the observation that there are additional risks and our knowledge of the returns to the marijuana grow-op business provide a mechanism for determining the number of marijuana grow-operations. This is discussed in the next section.

How Many Grow-Ops Are Out There?

One of the enduring problems facing anyone interested in the illegal, or "black," or even gray economy, is to derive an estimate of the underlying level of total activity from the sample of those that are detected. There are problems in doing this. A few might be catalogued under some broad headings:

- sample selection—only the unlucky or the least capable are caught;
- varying intensity of effort on the part of the authorities—more police "fishing" means a higher catch, at least initially; and
- an uncertain feel for what the alternatives are facing the agents who are thinking of going into illegal production—can they find a remunerative line of work in the legal sector, or are their alternatives really all about illegal alternatives to, say, marijuana production?[23]

This section proposes one calculation method to infer the number of grow-ops in British Columbia. More generally, it is a technique that could be used in a number of situations both current and historical. Although one may disagree in detail with *every* aspect of the analysis, it also provides a target to classify the underlying variables that may be important to any analysis of uncounted activities.

The approach

The underlying characterization is of the grow-op as a profit maximizing activity in which the value of output less costs, relative to the value of assets, yields the rate of return to assets. For each crop of a grow-op, all costs are fundamentally variable, so that we can write the rate of return as relative to costs.[24]

If the industry is in equilibrium, then the return on capital (or costs) is equated to the rate of return

22 That is, with only a 90 percent chance of realizing your sales, the expected rate of return becomes: ((0.9 x (½ x $76,000) - 24,500)/24,500).

23 There is still plenty of disagreement about the number of marijuana grow operations in British Columbia. Mark Hume of *The Globe and Mail* of January 12, 2004 reports: "Police estimate 2,000 to 3,000 grow-ops are producing BC bud in Greater Vancouver" (p. A2). On January 31, 2002, however, the *Vancouver Sun*'s Scott Simpson reports that the head of the Vancouver drug squad, Inspector Kash Heed, "could not estimate the number of growing operations in Vancouver, but said the number for the Lower Mainland has been pegged as high as 15,000" (*http://www.mapinc.org/mjcn.htm*). Interestingly, on a different page of the January 12, 2004 *Globe and Mail*, Peter Cheney reports police estimates that there are now 15,000 marijuana grow operations in Ontario (p. A6).

24 The alternative is to assume that the capital is used for a number of crop cycles. This would have the effect of increasing the value of output relative to the asset base. Consequently, this assumption biases the return to growing marijuana downward. The "true" returns on invested capital are likely to be higher.

in other industries or activities on the margin. This is the key observation underlying the estimation of the total number of illegal activities. It is what links the unobserved illegal activity to the known, legal world.

More formally, we write the value of output, PQ (price times quantity) less cost, C, relative to the value of capital, or in this case, cost. This gives a rate of return to investment (cost) in a particular year.

Thus R is a return over costs and looks like:

1. $R = [PQ - C]/C$

The value of output less cost is net income, PQ-C, during the year, and the return over costs is akin to the usual calculation of the rate of return to capital. If we believe that the industry is in equilibrium, about which more will be said later, then the return on capital (or costs) is equated to the rate of return in other industries or activities on the margin. Thus $R = R^*$, where R^* is the market rate of return.

Unlike the market, however, a grow-op includes ingredients of extraordinary risk not captured by legal market entities. Let us add a probability of getting caught[25] in a grow-op and consequently the risk of losing the entire crop. If the probability of getting caught is π, then the harvester has a $(1-\pi)$ probability of being able to sell quantity Q at price P. Compared to a riskless sale, this lowers the return to any given investment.[26]

2. $[(1-\pi)PQ - C]/C = R^*$

The left-hand side tells us that the harvester has a $(1-\pi)$ probability of being able to sell quantity Q at price P. Compared to a legal sale, this lowers the return to any given investment. The investor is assumed to lose the costs, C, whether the crop can be sold or not.

The expected return is equated to the return that the investor can get in any other sector of the economy, R^*. In effect, we assume that the potential investor in the marijuana business is faced with two options: Our potential producer can invest in those activities that are legal and receive a normal rate of return of R^*; or our potential producer can invest in a grow-op that includes an extraordinary risk of crop loss.

A refinement

The market rate of return, R^*, constrains the amount of investment in marijuana grow operations. If more and more people get into the business, eventually it will drive the return below that which could be made in other business activities. This limits the size of the sector. Symmetrically, if the return to marijuana grow-operations is higher than the return in other activities, this leads to more investment going to the marijuana industry, eventually driving the return toward the market average. This basic framework may not fully capture the essential constraints on an illegal activity. Do potential growers of marijuana view the market return on funds as relevant in assessing their alternatives? If one were loaning funds to a grow-op producer, the lender may insist on a risk premium associated with the loan so that the constraint associated with an equilibrium in the

25 In this context, "getting caught" includes being shopped by unscrupulous competitors, as well as having your crops catch fire, or simply be stolen by thieves. A tip apparently led to the discovery of a "massive" hydroponic operation in Barrie, Ontario, in the old Molson brewery—a site in plain view of Highway 400 (*The Globe and Mail*, January 12, 2004, p. A1, A6.) In Vancouver, police speculate that a marijuana grow-operation is invaded each day by competitors.

26 The investor is assumed to lose the costs, C, whether the crop can be sold or not.

marijuana growing business is not the market return, R^*, but a return that is risk-adjusted above those associated with legal investments. As a result, the cost of funds that this group faces carries a risk premium relative to that of legal investments.[27]

This suggests an expression like 3 is relevant to the basic equilibrium:

3. $[(1-\pi)PQ-C]/C=R^*+\pi$

which equates the expected return on the left-hand-side to a higher-than-legal-market return by an amount of the risk, π. Although the risk may not simply be additive, Appendix B derives a form that is consistent with 3.

Calculating the number of grow-ops

How does all this help with a calculation of the number of grow-ops in British Columbia?

We need to assume something about π. We assume that it is the risk of being busted by the police.[28] If we assume that only the police bust grow-ops, then we can develop a measure of the total number of grow-ops in the province.

To see this, recall what we "know" in this context:[29]

- We know the price of the product (see appendix B)
- We know the quantity of product for each operation—or at least we know the average output of those that are busted.
- We know the cost of the operation, although there are a few nagging issues that make this a more speculative calculation than the other data.
- We know the market return on legal enterprises—although this can be argued, the range of variation is likely not to matter much as will become apparent in the calculation.
- Finally, we also have a measure of the number of operations that have been busted around the province.[30]

These data are sufficient to calculate the number of grow-ops. To see this, first consider the variable, π. Since π is the probability of being busted, we can think of π as being the ratio of busts relative to the total, T, the (unknown) number of grow-ops:

4. $\pi=B/T$

27 Note that this is not the same as another experiment: should a person participate in the legal or illegal market? In this case, clearly the decision is based on R^*.

28 It also should include any other risk associated with being illegal rather than legal, e.g., lack of resources for redress of theft, extras security, and the like. Underestimating the risk will underestimate the number of grow-ops.

29 In this context, "know" is speculative under the best of circumstances.

30 This, of course, is police busts. It should also include "busts," or thefts, or any other event that reduces the ability to sell the final product on the left-hand side of the equation. As discussed earlier, some reports have marijuana "rips" at one a day in the Vancouver area alone. Consequently, these calculations that use only police data to estimate the number of marijuana grow operations are very conservative.

Table 4: The Effect of Different Assumptions for Estimating the Number of Grow-Ops in BC

Actual Police Grow-op Busts	Assumed Return to Legal Activities	Assumed Ratio of Value to Cost	Market Return is R*		When the Return is risk Adjusted, R* + π	
			Implied Total Number of Grow-ops	Implied Probability of being Busted	Implied Total Number of Grow-ops	Implied Probability of being Busted
B	R*	PQ/C	T	π	T	π
2,800	10%	5.0	3,590	0.78	4,308	0.65
		4.5	3,706	0.76	4,529	0.62
		4.0	3,862	0.73	4,828	0.58
		3.5	4,083	0.69	5,250	0.53
		3.0	4,421	0.63	5,895	0.48
		2.5	5,000	0.56	7,000	0.40
		2.0	6,222	0.45	9,333	0.30
		1.9	6,650	0.42	10,150	0.28
		1.8	7,200	0.39	11,200	0.25
		1.7	7,933	0.35	12,600	0.22
		1.6	8,960	0.31	14,560	0.19
		1.5	10,500	0.27	17,500	0.16
		1.4	13,067	0.21	22,400	0.13
		1.3	18,200	0.15	33,200	0.09
		1.2	33,600	0.08	61,600	0.05

Since we know the number of operations that have been busted by the police, B, everything is "known" (however imperfectly) except for T, the total number of grow-ops at risk. That is, we know P, price, Q, quantity and R*, the rate of return on legal economic activity.

Some manipulation gives us the following expression:

5. $\pi = B/T = [[(PQ/C)-(1+R^*)]/[1+(PQ/C)]]$

or, finally, an expression for the total number of grow-ops:

6. $T = B.[1+(PQ/C)]/[(PQ/C)-(1+R^*)]$

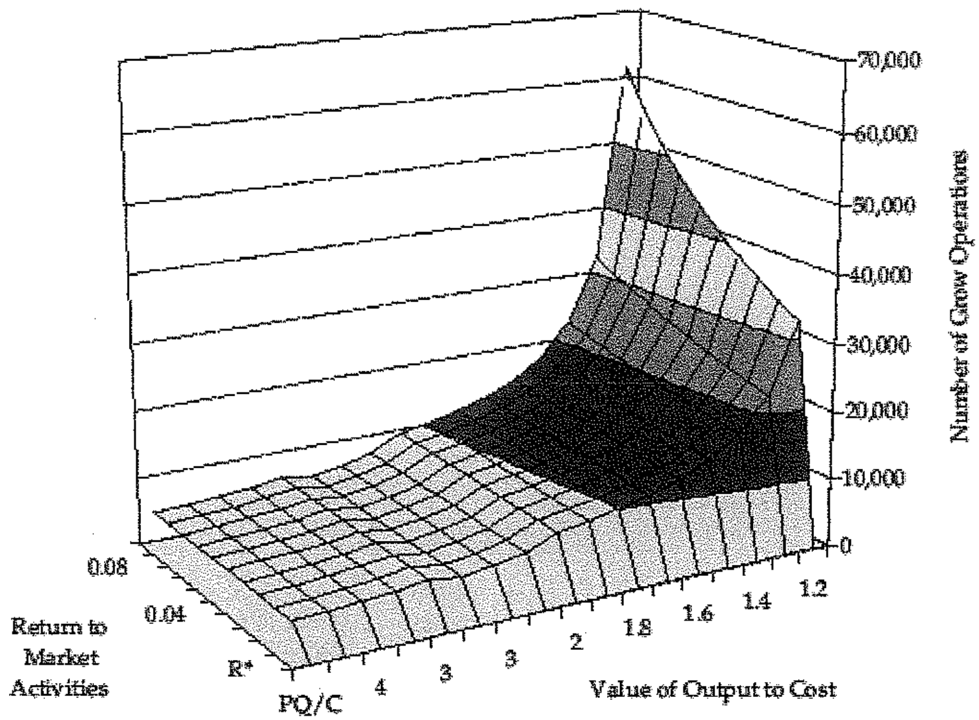
So what do the numbers look like? To illustrate: Let B = 2,800[31]; let R* = 10%; let (PQ/C) = 5

7. $T = 2{,}800.[(1+5)]/[(5-(1.10)] = 2{,}800.[6/(3.9)] = 4{,}308$

Table 4 reports what the theory implies for the number of grow-ops in British Columbia using various assumptions about the ratio of the value of output to costs. From the estimates in table 3, the number of grow-ops would be between 10,500 and 17,500 depending on the approach to risk. In later sections I use the 17,500 figure as I believe it best characterizes conditions in BC.

31 This is the number of "founded" cases in 2000 in all of British Columbia (Plecas *et al.*, 2002, p. 27.)

Figure 1: Number of Marijuana Grow Operations as a Function of the Value of Output and Rate of Market Return



tached) is plotted on the "y"-axis; and the "Number of Grow-ops" is along the vertical axis. Although not plotted, the value of π, the probability of being busted, like T, is a calculated value.

Estimates of the total number of grow-ops applied to the regions of British Columbia

The most recent characterization of the number of grow-ops in British Columbia is to be found in Plecas *et al.*, 2002. For the year 2000 they suggest a figure of 2,808 incidents of busted grow-ops in British Columbia.

We can see the implications of the model by region if we are willing to go with a particular value of the rate of return and the value of output relative to costs. Table 5 takes model 2 in which the rate of return includes an explicit risk premium, and uses the value 1.5 for the ratio of the value of output relative to costs.

Although interesting, because they indicate the likely scope of the marijuana industry geographically, yearly variations in table 5 are

Table 5: Implied Number of Grow-ops by Region

District	1997	1998	1999	2000
Greater Vancouver	2,975	4,188	5,625	8,394
Fraser Valley	775	1,025	1,394	1,756
Squamish-Lillooet	81	106	106	206
Mainland/Southwest	3,831	5,319	7,125	10,356
Nanaimo	613	725	731	963
Comox-Strathcona	456	563	731	888
Capital	563	450	738	619
Cowichan Valley	275	519	581	406
Sunshine Coast	50	219	213	156
Alberni-Clayoquot	88	113	119	113
Powell River	—	100	94	119
Mount Waddington	38	63	75	56
Vancouver Island/ Coast	2,081	2,750	3,281	3,269
Thompson-Nicola	294	575	519	506
Central Okanagan	238	350	506	519
Northern Okanagan	169	313	294	500
Okanagan-Similkameen	175	231	269	344
Columbia-Shuswap	156	156	206	225
Thompson/Okanagan	1,031	1,625	1,794	2,094
Fraser-Fort George	144	175	269	406
Cariboo	144	181	163	381
Cariboo Overall	288	419	431	788
Central Kootenay	200	281	475	288
Kootenay Boundary	81	238	244	131
East Kootenay	88	125	138	181
Kootenay Overall	369	644	856	700
Kitimat-Stikine	63	75	75	156
Skeena-Queen Charlottes	44	38	31	13
Central Coast	6	—	—	6
North Coast Overall	113	113	106	175
Bulkley-Nechako	81	44	50	119
Stikine (region)	—	6	13	—
Nechako Overall	81	50	63	119
Peace River	25	31	69	44
Northern Rockies	—	6	13	6
Northeast Overall	25	38	81	50
Province Overall	7,819	10,956	13,738	17,550

Assumptions: Ratio of Sales to Costs (PQ/C) = 1.5
The Rate of Return to Enterprise: $R^* = 10\%$
π, the Probability of being Busted, is 16%
The Opportunity Cost for the grower is $(R^*+\pi)$

Table 6: The Export Consequences of Different Estimates of the Number of Grow-Ops

Value of Output to Cost Ratio* PO/C	Number of Grow-Ops*	Marijuana Production in British Columbia (metric tons)**	Marijuana Exports*** from British Columbia (metric tons)	Retail Bulk Value of Exports**** (Billions of dollars)
5.0	4,306	102	72	0.36
4.5	4,529	108	77	0.39
4.0	4,828	115	84	0.42
3.5	5,250	125	94	0.47
3.0	5,895	140	109	0.55
2.5	7,000	166	136	0.68
2.0	9,333	222	191	0.96
1.9	10,150	241	211	1.05
1.8	11,200	266	236	1.18
1.7	12,600	299	269	1.34
1.6	14,560	346	315	1.58
1.5	17,500	416	385	1.92
1.4	22,400	532	502	2.51
1.3	32,200	765	735	3.67
1.2	61,600	1,464	1,433	7.17

*See table 4 for the basis of the estimates.
**Assume 33.3 grams per plant and 180 plants per grow-op (Plecas et al.), and 4 crops per year.
***British Columbia exports are BC production less BC consumption. National consumption from table 1. BC consumption is 13 percent of the national total, adjusted for consumption per user or 30,600 kg.
****Assumed price of $5,000 per kg. (see table 2).

driven entirely by the number of busts in each region. Increased enforcement arising from local conditions are much more likely to have an impact in a region than they are in the overall scheme of things.

Potential British Columbia marijuana exports

Using the estimate of the number of grow-ops from table 4 will also allow an estimate of the total quantity of marijuana grown in British Columbia. Contrasted with the implicit demand of table 1, it gives a rough and ready sense of the level of exports by the industry. In table 6 the first column reports different possible output to cost ratios that are reasonable in assessing the British Columbia marijuana industry. Each of these numbers gives rise to an estimate of the number of grow-ops in the second column. The third column derives the implied quantity of production (measured in metric tons) associated with each of the estimates of the number of grow-ops. Since exports from British Columbia are the quantity of production less the amount absorbed domestically within the province, the estimate of the quantity of exports is generated by using the production figure of column four with the consumption from table 1 adjusted for the size of the province of British Columbia.

The value of exports is measured at an assumed price of $5,000 (Canadian) per kilogram. This is a bulk value since it is purchased and shipped in quantity rather than cigarette by cigarette. Of course the value of the exports at final sale will

Table 7: The Value of Grow-op Marijuana Relative to GDP in British Columbia

	1997	1998	1999	2000
BC's Gross Domestic Product (GDP) (billions of dollars)	114.4	115.6	120.6	130.6
Grow-op Sales as a Percentage of BC GDP	1.1%	1.6%	2.4%	2.8%

depend upon the prices in the US and will be substantially greater.

A reasonable supposition, given that British Columbia absorbs slightly more than its 13 percent of Canada's population, is that British Columbia's consumption is roughly between 21 and 54 metric tons (from table 1). The quantity of output is vastly greater: between 100 and 1,460 metric tons.[34] It is reasonable to conclude that most of the British Columbia crop is exported to the United States or in some measure to the rest of Canada. The estimate that appears to me to be the most reasonable (albeit tentative) generates exports of nearly $2 billion in year 2000.

The size of the British Columbia marijuana industry

To put this into some kind of perspective, table 7 measures the value of production of marijuana from grow-ops at between 1 percent and 2.8 percent of British Columbia's Gross Domestic Product (GDP) that was roughly $130 billion in 2000.[35] However useful this is insofar as it scales the cost of domestic production by comparing the wholesale value of BC's marijuana crop to GDP, the ratio is inflated since we are using final sales and not the value-added of the marijuana grow industry.[36]

To measure the value of the marijuana crop at final sale prices properly, we need to use the prices associated with the quantities that are sold on the retail market: the gram, ounce, pound, kilo etc., amounts since prices per unit vary by quantity. Similarly, prices vary by region and by type of product. Using a statistical analysis of price per gram as a function of quantity sold, region, urban-rural, and other variables, we can construct a retail price model for sales. If we were to assume that marijuana were sold by the pound, then in British Columbia in the year 2000, the retail price is about $2,600 in urban British Columbia. If we were to assume that marijuana was sold by the ounce, then it would be worth about $4,100 per pound on average. By the cigarette, a pound would sell for $7,800.

34 That is, with 7,000 to 17,500 grow-ops each producing about 13.3 kilograms annually, the total harvest is between 168 and 420 metric tons. Specifically, 33.3 grams per plant x 180 plants x 4 crops per year = 24 kilograms per year per grow-op.

35 Sales to the general public are assumed to be in the ounce range. In any case, table 2 permits the reader to calculate his or her own valuation.

36 Since GDP measures value added rather than final sales, the size of the marijuana industry appears too large relative to other industries. Rather than try to "guild the bud" by further refinements of the value added of the marijuana grow operations, the comparisons should be taken for what they are: an effort to get some sense of the overall scale of economic activity in the marijuana industry in BC. Obviously we can construct a value-added measure consistent with our representative grow-op of table 2, but this is placing a great deal of weight on a rather speculative calculation.

Table 8: The Value* of the BC Marijuana Harvest by Region Measured at "per Cigarette" Values (in millions of dollars)

District	1997	1998	1999	2000
Greater Vancouver	950	1,328	2,219	3,422
Mainland/Southwest	1,224	1,687	2,937	4,222
Vancouver Island/Coast	665	872	1,356	1,555
Thompson/Okanagan	329	515	740	854
Provincial Total	2,497	3,474	5,664	7,156

*The assumptions underlying quantities for this table are the same as those for table 5.

So what are the bounds to a measure of retail value of sales? To answer this we need a measure of the price of what is sold. Significantly, the unit in which the marijuana is sold is an important consideration. From our estimates in table 2 and the supporting discussion in appendix A, we know the relationship between price per gram and quantities sold—be it a fraction of a gram, or by the kilo, and various quantities in between.

To carry this to the extreme, suppose that the British Columbia producers' crop was to be valued at the per cigarette street cost: the smallest and most expensive retail unit. Table 8 gives a sense of the values.

Table 8 reflects the retail value of the product from each of British Columbia's regions. The producers do not, of course, receive these amounts. Like many agricultural products, the "middle-man" receives much of the difference between the final sale price and the original producer. Transportation, packaging, marketing, and risk of confiscation by various competitors and law enforcement are all part of the difference.

Although the values do not reflect the actual receipts by the growers in each region, the numbers do reflect an estimate of the contribution to ultimate street sales made by each region should the final product be sold at British Columbia retail prices in British Columbia. Estimating the "true" street value of the actual product would necessitate knowing exactly where final consumption took place: both at home and in the United States.[37]

Although many underground activities have consequences for society ranging from alcohol prohibition of the 1920s to drug prohibitions today, economists have had a difficult time in describing the extent of production. The British Columbia marijuana industry is a good place to begin to study this problem. While decentralized, the characteristics of the grow-ops are relatively well known, and there is a considerable volume of product, much of which heads to the US.

37 There is a substantial marijuana trade with the US.

Why Does it Happen in British Columbia?

Although current federal initiatives to decriminalize the possession of small quantities of marijuana may change the traditional location of marijuana production, one of the enduring, frequently-asked questions is why it is that marijuana cultivation and consumption have traditionally taken place more openly in BC than elsewhere in Canada. Is it British Columbia's *indoor* climate? What is different on the Coast?[38]

Although there is no simple answer to such a question, several statistical observations may bear on the issue. One outstanding statistic is that possession incidents are not "cleared by charge" as frequently in British Columbia as they are in Canada's other provinces.[39] Although there are differences between BC and the rest of Canada for charges with respect to other drugs, the difference is greatest with respect to marijuana. Second, a look at the pattern of arrests and penalties facing marijuana growers in Vancouver also gives a sense of the consequences for (some) marijuana growers.

Table 9 reports drug incidents and charges for 2001. Only 13 percent of possession offences in BC are cleared by charge. Elsewhere in Canada over 60 percent of possession offences are cleared by charge. Even though BC has nearly twice as many offences relative to population as the rest of Canada, clearing by charge is one-fifth of that elsewhere in Canada. The reasons for such a pattern may depend upon the courts, the prosecutors, or the police, but it is surely indicative of a difference in perspective at some level in the enforcement of the law.[40]

Is clearing by charge the relevant data for explaining the size of the British Columbia marijuana industry? Are fines lower here than elsewhere? Probably not, but why this industry has been so successful in British Columbia and less so elsewhere remains a topic of serious interest. In that spirit, the next section considers the effect of being caught ("busted") in a marijuana grow-operation. Although I do not have comparative data on those caught for growing marijuana elsewhere in Canada, the kinds of punishments in British Columbia are consistent with a marginal level of deterrence.

What happens to marijuana growers?

Local conditions in British Columbia obviously play a role in the production of marijuana. If British Columbians really are producing the massive quantities of the drug that I have suggested, is-

38 Recent high-profile police busts in Ontario and Quebec make it clear that marijuana growing is no longer unique to British Columbia.

39 Actually, BC is far less likely to clear offences by charge than the rest of Canada for almost any drug possession offence. "Clearing by charge" means that a file is sent to Crown prosecutors for action on a criminal charge. Files can be closed in other ways if, for example, the person the police believe committed the crime has died or is being charged with a more serious offence on another charge.

40 The observation that BC does not often charge for marijuana possession (nor, for that matter, other drug possession), and yet the province has a particularly potent marijuana crop is a puzzle. Theory would suggest that if enforcement is very enthusiastic, then the crops would be small and of high potency. A less strict criminal enforcement environment would be expected to produce crops that are less strong and less intensively cultivated. BC appears to be the opposite.

Table 9: Drug Crimes and Drug Charges in Canada and British Columbia, 2001

Incidents Known to the Police	Actual Number in Canada	Actual Number in BC	BC as a Share of Canada	Incidents Cleared by Charge in BC	Incidents Cleared by Charge in Canada Net of BC
Heroin—Possession	504	367	73%	37%	80%
Trafficking	403	258	64%	74%	89%
Importation	58	13	22%	23%	22%
Heroin—Total	965	638	66%	51%	75%
Cocaine—Possession	5,478	1,744	32%	38%	82%
Trafficking	6,265	1,876	30%	70%	81%
Importation	490	53	11%	28%	36%
Cocaine—Total	12,233	3,673	30%	54%	79%
Other Drugs—Possession	3,982	675	17%	25%	59%
Trafficking	2,472	329	13%	43%	76%
Importation	1,302	231	18%	17%	14%
Other Drugs—Total	7,756	1,235	16%	28%	57%
Cannabis—Possession	49,639	11,757	24%	13%	62%
Trafficking	11,124	2,098	19%	62%	73%
Importation	739	203	27%	4%	21%
Cultivation	9,122	3,477	38%	27%	37%
Cannabis—Total	70,624	17,535	25%	22%	61%

Note: 2001 population: CANADA: 31,081,887; BC: 4,095,934. BC's population is 13% of Canada's.
Sources: Statistics Canada, *Canadian Crime Statistics 2001*, cat. no. 85-205 XIE, pp. 17 and 37.

sues of local law enforcement are clearly part of the cost of doing business. This section explores some of the consequences from fragmentary data arising from charges and convictions when grow-operation busts take place. Although the discussion is entirely in the context of Vancouver data, since Vancouver is an important source of British Columbia marijuana it is clearly a significant environment. The first subsection looks at the consequences for being caught by the Vancouver police in a marijuana grow-operation over the 1996-1999 period.[41] A second subsection characterizes those who are caught to see whether the punishments meted out give any hint about their effectiveness in deterring illegal marijuana grow operations. There are obviously many other important questions to be answered, such as connections with organized crime, and the financing and money laundering and trading for other illegal drugs, but the data are not able inform us on these issues.

Sentencing those found guilty

Table 10 details the outcomes for those who were sentenced after being convicted of offences associated with the busting of marijuana grow-ops in Vancouver. The first column indicates the num-

41 The raw data for this section relies on Wickstead, "Who Wants to be a Millionaire?" It relates to Vancouver between 1996 and 1999.

ber of days of the sentence. The second column gives the percentage of all those convicted (for whom we have relevant data, as some were still awaiting sentencing), and the third column reports the cumulative percentage of those sentenced, up to and including the number of days indicated.

Most who were charged and convicted received no jail time. In table 10, the first row indicates that 55 percent of convictions received zero days' jail time. Five percent of those convicted received a single day in jail. Another 8 percent received sentences between 1 day and 31 days, and still another 8 percent received 60 days. Some 11 percent were sentenced to 90 days. Sentences for the remaining 11 percent were spread out from 120 days to 540 days.

A number of ingredients go into sentencing. For the data available, the number of prior convictions (of any type) and the size of the operation in which the convicted person was caught appear to be positively associated with the length of the sentence, although it is clear that much more than those factors must influence sentencing.

Statistical analysis reveals that an additional prior conviction will increase the length of the sentence by on average, a little over three and one-half days.[42] Similarly, the value of the grow-operation affects sentencing. A $100,000 increase in the imputed value of the grow-op tends to add over 16 days to sentencing. However, what is equally interesting is that these two variables—prior convictions and the value of the operation—account for only about 16 percent of the explanation of the length of sentence. "Other factors" explain the length of sentences associated with marijuana grow-op busts. Whether this has to do with the judge in whose court the case is heard, the prosecutor who works the case, the defense counsel who defends, or specific details of the case not captured by our data, clearly more research has to be done to reach an understanding of the reasons for the observed durations of sentences.

Table 10: Sentenced Jail Time for Those Convicted in Marijuana Grow-Operations

Days	Percent Sentenced	Cumulative Percent
0	55.3	55.3
1	4.4	59.6
30-46	7.9	67.5
60-61	7.9	75.4
90	11.4	86.8
120	1.8	88.6
150	0.9	89.5
180	6.1	95.6
240	0.9	96.5
270	0.9	97.4
540	2.6	100.0
Total	100.0	100.0

Note: 114 observations.
Source: Wickstead, 2000a.

As might be expected, cultivation and drug trafficking were the majority of offences for which there were convictions. Table 11 indicates the range of days for those convicted of cultivation. One half, 50 percent, received no jail time. Two received 540 days. All but a handful received 90 days or fewer as a sentence. Of course not all these days are actually spent in jail since after one-sixth of a sentence, roughly, a convicted person is eligible for parole, and days in jail before conviction count for two days served after conviction.

42 See appendix E for the statistical details of the analysis.

Table 11: Days Sentenced for Cultivation Offence

Days of Sentence	Percent	Cumulative Percent
0	50.0	50.0
1	6.0	56.0
30-59	8.4	64.3
60-61	9.5	73.8
90	13.1	86.9
120	2.4	89.3
150	1.2	90.5
180	6.0	96.4
240	1.2	97.6
540	2.4	100.0
Total	100.0	100.0

Note: 84 observations.
Source: Wickstead, 2002c.

Outside of the loss of your equipment and product, how important are the personal costs for having been convicted in a marijuana grow operation dismantled by the Vancouver Police Department? Who are some of the people who are growing marijuana and are they deterred from returning to the business? To explore this issue we can look at some of the current producers' past run-ins with the law. What do their criminal records reveal?

Time between convictions

Although charges are not the same as convictions, past convictions and current charges provide their own feel for the drumbeat of suspect economic activity in the marijuana trade. Figure 2 plots the histogram of the days between charges for those apprehended in current grow-ops. Prior charges were varied, although many relate to marijuana.

The distribution in figure 2 (reported in the legend) shows that the average time between convicted offences is about 14 months. In the figure, the horizontal axis shows the number of days between convictions. The vertical axis shows the frequency with which each number of days between charges is observed. The median is 11 months (328 days). This means that as many are charged in under 11 months as after 11 months. So among those with more than a single arrest, if charges are leveled this frequently, it is reasonable to suggest that whatever it is that many of these people are doing, they are continuing to do it![43] From the point of view of an ongoing business, court time, or a charge, are simply part of the costs of doing business.

This sense is heightened by the data in table 12 that reports the outcome of all the charges for which data are available about those who were charged in the Vancouver police busts, many who have had multiple incidents in the past.

The first column of table 12 reports the number and proportion of all those who are currently charged with running a grow-op (or who face other charges arising from the arrest) and who have been convicted in the past. Of those now charged, about 70 percent were convicted and only 3 percent acquitted. Twenty-two percent had charges stayed with four percent discharged or dismissed.

Among the 670 convictions, there were 237 fines imposed (a little over a third of those convicted.) These fines averaged $1,167. To put this into per-

43 Two observations were excluded as the time between charges was 4,500 and 5,000 days. These were well above any other observations. The data in the text use a cutoff of 2,000 days. The mean for the whole sample, including the two very high observations, was 551 days.