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Estimated Cost of Production for Legalized Cannabis

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Estimated Cost of Production for Legalized Cannabis

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Abstract
This paper tries to estimate post-legalization production costs for indoor and outdoor cannabis cultivation as well as parallel estimates for processing costs. Commercial production for general use is not legal anywhere. Hence, this is an exercise in inference based on imperfect analogs supplemented by spare and unsatisfactory data of uncertain provenance. While some parameters are well grounded, many come from the gray literature and/or conversations with others making similar estimates, marijuana growers, and farmers of conventional goods. Hence, this exercise should be taken with more than a few grains of salt. Nevertheless, to the extent that the results are even approximately correct, they suggest that wholesale prices after legalization could be dramatically lower than they are today, quite possibly a full order of magnitude lower than are current prices.

1. INTRODUCTION

This paper tries to estimate post-legalization production costs for indoor and outdoor cannabis cultivation as well as parallel estimates for processing costs. A byproduct of this analysis is some insight into the scale of utilization of various factor inputs.

Commercial marijuana production and processing for general or recreational use is not legal anywhere, not even (as is often incorrectly asserted) in the Netherlands. Hence, this is an exercise in inference based on imperfect analogs supplemented by spare and unsatisfactory data of uncertain provenance. Broadly speaking there are two kinds of analogies: Illegal cannabis production and legal production of agricultural products that might for various reasons be seen as similar to cannabis. Neither presents a sound foundation for extrapolation, and the extrapolation is fraught with conjecture and reliance on grey literature rather than the scientific literature. While some parameters are grounded in standard academic literature or government agency estimates, many come from the gray literature[1] and/or conversations with others making similar estimates, marijuana growers, and farmers of conventional goods. The reader is cautioned that this exercise, while a good faith attempt, should be taken with more than a few grains of salt.

A particular concern is uncertainty about potential process innovation and automation engendered by larger operating scales and freer information flow. We generally assume that competition will drive productive efficiency toward to the top of the range of practices seen currently, but do not consider the possibility of fundamental innovation.

Nevertheless, to the extent that the results are even approximately correct, two primary conclusions are that: (1) Even production costs of marijuana when it is illegal do not seem large enough to account for current price levels[2] and (2) Production costs after legalization could be dramatically lower than they are today, quite possibly a full order of magnitude lower than are current prices.

2. COSTS OF INDOOR ILLEGAL CANNABIS PRODUCTION

We attempt to estimate production costs for three modalities: (1) private, non-commercial 5' x 5' indoor hydroponic grow with lights, (2) devoting an entire 1500 square foot residential house to indoor growing with lights as a commercial operation, and (3) greenhouse-based commercial growing. The distinction between the second and third comes primarily from different electricity, land, and structure costs, and also the number of harvests per year.

2.1: Materials and Consumables

The grey literature is rich with very detailed explanations of how to grow marijuana, and price quotes for the equipment and materials are readily available online, so it is possible to estimate the costs of materials and consumables.

A Carnegie Mellon Heinz student under our supervision generated a cost estimate for a hypothetical hydroponic set-up in a 5' x 5' space that is allowed under section 3.ii of The Regulate, Control, and Tax Cannabis Act of 2010.[3] He concluded the consumables (growing medium and nutrients) totaled on the order of $300 per harvest. Electricity at 40

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[1] We cite primarily Cervantes (2006) and Edwards (2006) since they are readily accessible books. We endeavored to cross check statements in those books with various web sites and blogs. Still, mere repetition of a statement in multiple non-refereed sources is no guarantee of accuracy (cf., Reuter, 1984); at best it means we are capturing some nebulous community's conventional wisdom, but not necessarily objective facts.

[2] Indeed, there are already media reports of declining wholesale prices (e.g.,), although official price series are more stable.

[3] Thanks to Josh Swiss for this analysis.

watts per square foot and $0.14 per kwH added another $200 per harvest.[4] Durable items (fan, lights, air stone, pump, tubing, sheers, etc., apart from light bulbs) totaled $1,250 - $1,500, but if they could be amortized over four harvests per year for five years shrank to $60 - $75 per harvest.[5] Interesting, light bulbs (with an assumed life time of one year) were a non-trivial cost item, at $27.50 per harvest. Altogether, the student estimated costs per harvest in the vicinity of $600.

Yield estimates are grounded in Toonen et al.'s (2006) study of 77 illegal, indoor growing operations in the Netherlands. They found a median planting density of 15 plants per square meter, or 1.4 plants per square foot, and an average yield of 1.2 ounces of saleable material per plant per harvest.[6] That translates to 0.105 pounds per square foot per harvest or 2.625 pounds per 25 square feet per harvest. Combining this with the $600 figure derived above, the materials and consumables cost per pound is about $225 per pound.

That is, a well-run 5' x 5' hydroponic grow producing 4 harvests per year might yield 10.5 pounds per year with tangible costs of $225 per pound--$75 per pound for electricity and the remaining $150 per pound for other factors.

These costs work out to be quite consistent with those described in a Dutch case study described by Cervantes (2006, p.148). That case study described three harvests: (1) a modest 8.4 pounds grown on 128.6 square feet at a cost of $5,647, (2) a subsequent investment of $8,220 that doubled the area cultivated and improved methods, yielding 27.6 pounds, and (2) a third harvest in the full space of 30.2 pounds whose incremental cost was only $1,882. That works out to ($5,647 + $8,220 + $1,882) / (8.4 + 27.6 + 30.2) = $238 per pound.

Of course the costs per pound in Cervantes' case study decline if the first two harvests are effectively investments to get the operation running. The cost per pound during the third harvest was only $62 per pound, lower even than just the cost of electricity estimated for

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4 This assumes 24-hour light for the first 30 days and 12-hours of light for the remaining 60 days. That's 1,440 hours of light per harvest. 40 watts per square foot (mid-range from Edwards, 2006) times 25 square feet conveniently gives 1 kwH per hour of lighting. Electricity prices from US Energy Information Administration (2009).

5 Amortizing equipment costs at 20% per year is a common practice in budgeting greenhouse operations for legal crops (e.g., Ohio State University Extension, 2008), but it has not specific empirical basis with respect to marijuana growing equipment in particular; it is a good example of a parameter grounded in judgment not data. Assuming four harvests per year is typical of indoor operations, allowing 30 days in the clone/vegetative and 60 days in the flowering stage.

6 One source of confusion in the literature is whether yields are quoted per square foot of flowering plants or per square foot of total growing area (including area for clones and plants in the vegetative state). We presume Toonen et al.'s yields pertain to all area with plants, but there are four harvests per year. Some estimates are based only on the part of the grow area with flowering plants, but then assume six harvests per year since the plants only spend 60 not 90 days in that area.

the 5’ x 5’ grow. The longer the operational life over which the initial investment could be amortized, the lower the total cost, but within two years of four harvests per year (i.e., the three harvests described by Cervantes plus a hypothetical five additional harvests like the third), the cost could be $116 per pound.

There are at least three reasons why Cervantes’ case study costs were lower per pound: (1) Some materials might be purchased at lower unit costs when operating at such a largest scale (258.5 square feet vs. 25 square feet), (2) the case study took place in the Netherlands, where there is a good infrastructure for supporting such activities, and (3) Cervantes’ book is a how-to guide for marijuana growing and how-to guides may have an incentive to offer a favorable, not a representative case study. The third is a particular concern; we speculate that Cervantes case study may not be representative of average grow costs today, being something of a best case. Indeed, Cervantes describes the great importance of the two growers being able to tap the expertise of someone with considerable experience. However, after legalization when it becomes easier for such consultants to advertise their services and fewer people are trying to work their way up the learning curve with limited assistance beyond internet web sites, a favorable outcome in today’s term may become the norm.

For the sake of particular numbers, for indoor, lighted growing we will carry forward the electricity costs from the 5’ x 5’ grow (at $75, based on 40 watts per square foot), but consider a range of other costs from $50 - $150 per pound.

Electricity costs for greenhouse growing could be essentially zero if only natural light is used, but might still exist at some level if artificial lighting is used to control the flowering cycle. We will arbitrarily assume the upper end of that range is one-third of the cost of an indoor grow with purely artificial light.[7]

2.2: Labor

The grey literature is rich with very detailed explanations of how to grow marijuana, but generally does not provide precise estimates of labor requirements. This is not surprising. At present marijuana cultivation is a cottage industry, and labor hours per pound produced appear to vary enormously depending on : (1) skill level; novices take longer and produce less per plant or per unit area than do average growers, let alone the most skillful; (2) individual traits; two people at the same point on a learning curve may still have different productivity rates in the same way that some people consistently manage better yields than others from home garden plots; and (3) operational scale; marijuana cultivation involves many steps and amortizing the fixed or “set up” costs of those steps over a larger production volume greatly reduces the labor input per pound produced.

[7] This upper end guess is an obvious candidate for improvement in a refined analysis.

There are plausible arguments why legalization could positively affect labor productivity in all three respects. If marijuana production were legal and normalized, most workers would spend most of their careers further up the learning curve both because more would be full time workers, not hobbyists, and because companies in the business would be able to establish training programs for new hires. Likewise if marijuana production were just another industry, workers would sort into that industry based on affinity and natural ability. At present, the dominant selection filter determining who works as a marijuana grower is willingness to participate in illegal drug production, and there is no reason to think that subset of the population is the subset with the greatest skill at horticulture. Finally and most obviously, legalization would presumably allow economies of scale and better information exchange. E.g., it would be even easier for consultants to sell their expertise in productivity enhancing tricks of the trade than it is at present.

The extent to which these efficiency gains are realized may well depend importantly on how aggressively federal law enforcement officials investigate and prosecute marijuana producers. If federal enforcement agencies took a hands-off approach, then marijuana production in California could enjoy the efficiency gains characteristic of most industries in a competitive free market. At the other extreme, sufficiently aggressive federal enforcement might force production to remain dispersed and discrete, as it is today.

To be conservative, in our estimates of legalization's potential effects on production costs we will base our conjectures about labor productivity on the high-end of what can be achieved today, rather than factoring in hypothetical subsequent efficiency gains. Note: What we discuss in this section is just the labor effort involved in growing the marijuana; harvesting and processing stages are discussed in a different section, later in this paper.

However, we do presume that the labor wages would decline. That is, we imagine that even if federal law enforcement were to break up flagrant producers, it would seek to prosecute only the proprietors, not the laborers. So we imagine that industry wages would fall to the levels of other agricultural workers.

For present purposes we do not need to know what the current hourly wage rates are, but we did run across a number of statements in the grey literature suggesting that $20 to $25 per hour might not be atypical of cash payments.[8] By way of contrast, agricultural workers in California harvesting and tending legal crops typically cost the employer no more than $10, including whatever benefits are (or are not) provided. For example, O*NET (2010) cites an average wage for California nursery and greenhouse laborers of $8.60/hour.

[8] Often some of the compensation is in-kind or the labor is provided by someone with an ownership stake in the marijuana being processed. The $20 - $25 figure is meant to reflect instances in which the compensation arrangements reflected a straight wage.

Labor Cost for a Private 5' x 5' Hydroponic Grow

Perhaps the best way to think about the labor required for a private, non-commercial 5' x 5' grow is that it is akin to a serious hobby, probably not more than an hour a day once the set-up had been created. In many cases the labor would be provided by the person who owns (or rents) the physical space and the marijuana plants; that "proprietor" would not literally pay himself or herself in cash for the time.

Economists rightly note that there is an opportunity cost to uncompensated time. So a formal analysis might suggest imputing a charge equal to the average wage in the growers' legitimate, day job. However, that strikes us as not the best way to think about it given that growing plants is an enjoyable activity for a not small subset of the population.

We previously estimated that a well-managed 5' x 5' hydroponic grow can produce about 10.5 pounds of marijuana per year. A number of studies suggest that the average quantity of marijuana consumed per past-year user is close to 100 grams (Bouchard, 2008; Kilmer & Pacula, 2009, UNODC, 2009). So a single 5' x 5' home grow could provide enough marijuana for about 50 average marijuana users.[9] We would guess that at least one in 50 people generally and, hence, likely one in 50 marijuana users would enjoy gardening enough to find growing to be pleasurable, both in its own right and for the associated social pleasures of trading gossip about the process with other growers.[10] Hence, it does not make sense to cost this time as if it were work.

This is not to deny that skill and effort are required to grow marijuana (especially high quality marijuana); we are merely arguing that even if it were possible to estimate average hours involved and average wages of those who would have private grows, such a quantification would not improve the accuracy of the cost-estimate because it would overlook intangibles that are plausibly of the same order of magnitude.

Instead, we prefer to think of the production cost of home-grown, non-commercial marijuana as including both a tangible dollar cost and a non-commensurable additional in-kind donation of hobbyists' time (and space, as is discussed below).

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[9] 10.5 pounds * 453.6 grams per pound / 100 grams per person = 47.6. One could refine this calculation. The actual average is just shy of 100 grams, and the 10.5 pounds would likely all be sinsemilla, whereas the ~100 gram average is based on some mix of grades, including some lower quality. On the other hand, grams consumed per person per year might be higher after legalization. For the purposes of this present argument, greater precision would not change the basic argument.

[10] We stress the word "guess". We found no formal survey or estimate, but home gardening of legal plants (vegetables, flowers, etc.) is common enough to support multiple magazines, a cable television network, gardening clubs, and garden supply companies. The National Garden Association claims that 83% of American households participated in some sort of do-it-yourself indoor or outdoor lawn and gardening activity (http://assoc.garden.org/press/press.php?q=show&id=2617&pr=pr_nga), but that is a much broader definition than what is relevant here, which would be serious indoor gardening enthusiasts.

Labor Cost for a Commercial Growing Operation in a House
This section focuses on commercial indoor growing in houses. If marijuana were fully legal in all respects, including with respect to federal law, there would be no reason to grow marijuana in residential houses. Greenhouses are cheaper to build and maintain and take better advantage of natural light. However, one possible stance of federal law enforcement would be to enforcement federal marijuana laws against brazen growing on farms (in fields or greenhouses), but to ignore covert operation.

We will assume that a single, full-time person could manage a 1500 square foot house growing 1300 square feet worth of marijuana. (The 200 square foot difference allowing for walkways and other non-grow areas.) There are several reasons to think this is plausible. First, small groups of organized growers have been known to carry out such operations in multiple houses at once (Bouchard and Nguyen, forthcoming). Second, Cervantes (2006) case study involves two people with full time jobs cultivating approximately 260 square feet worth of marijuana without describing it as unduly burdensome outside of harvest time, and, as noted, harvest and processing labor is dealt with separately below. Third, it seems generally plausible based on the grey literature's descriptions of cultivation processes, although admittedly the grey literature tends not to quantify labor effort per step.

A typical productivity rate for intensive indoor growing is 0.1 pounds per square foot per harvest. To be consistent with the 5' x 5' grow estimates, we will use a figure of 0.105 pounds per square foot per harvest.[11] At four harvests per year that suggests 1300 * 0.105 * 4 = 546 pounds per house per year (usable, dry, sinsemilla grade). Assuming 2000 labor-hours per work-year, that suggests a labor productivity of roughly 4 hours per pound grown (exclusive of harvest and processing time), or $40 per pound at a labor rate of $10 per hour.

As an aside, we mentioned above that wages of $20 - $25 per pound came up frequently in our readings. So replacing those enforcement-risk inflated wages (Reuter and Kleiman, 1986), with wages typical of conventional agricultural workers would reduce production costs by about $50 per pound, even if there is no increase in labor productivity.

Labor Cost for a Commercial Greenhouse Growing Operation
There are many variants on greenhouse operations, ranging from essentially roofed outdoor growing with large plants to typical indoor operations (small, dense planting), but using a cheaper structure and supplementing electric lights with natural light.

[11] E.g., this is the rate implied by Tooney's (2006) figures, discussed further below.

We will envision the latter, but more or less arbitrarily imagine that greenhouse-based small-plant cultivation achieves only half the productivity per square foot as does production in houses, i.e., 0.2 pounds per square foot per year. Greenhouses offer less control of lighting than purely indoor grows, but Cervantes (2006) asserts that greenhouse operations can still achieve three harvests per year, vs. four per year with pure indoor. Our rounding down from ¾ to ½ the plant productivity per square foot is meant to reflect less densely packed growing areas (e.g., more walkway space for workers).

Greenhouse operations offer important labor efficiency benefits relative to house-based growing both from scale economies and simpler lay-outs (both for people and for HVAC control). Indeed, agricultural extension service estimates of hydroponic greenhouse operations for legal crops like tomatoes and lettuce typically estimate labor costs at $2 - $5 per square foot per year (OSU, 2008; Uva and Richards, 2000), which would translate to $10 - $25 per pound at 0.2 pounds per square foot per year. That is roughly half the labor cost per pound we estimated for house-based growing, where the emphasis was on productivity per unit area not per unit of labor cost.

2.3: Rent

Rent for a Private 5' x 5' Hydroponic Grow

For the same reasons discussed under labor costs, we prefer to think of the "rent" paid on a 5' x 5' private grow as an in-kind contribution of the recreational grower. However, if one wished to impute rent for indoor small-scale growing, one could use the same figure as for commercial indoor growing, which we derive next.

Rent for a Commercial Growing Operation in a House

Conceptually this calculation is simple; we simply want to charge the rent or all-in ownership costs of a typical 1500 square foot house. California housing markets make this highly dependent on the particular location. A 1500 square foot house in Malibu costs enormously more than in rural parts of California. Hence, this aspect of production costs is difficult to predict, and is heavily dependent on which if any California localities decide to allow and regulate commercial production.

The median price of residential housing in California is roughly $300,000.[12] An old saw is that landlords should think in terms of a 100:1 ratio of purchase price to monthly rent, suggesting annual rent of $36,000. Dividing by an estimated production volume of 546 pounds per year works out to a rental cost of $66 per pound.

There are many ways this calculation could be refined. For example, marijuana growers would gravitate toward cheaper than average housing; the marijuana plants do not care

[12] http://www.businessweek.com/news/2010-05-24/california-house-prices-rise-on-fewer-foreclosures-update1-.html.

about curb appeal or school district quality. On the other hand, there would presumably be some risk of federal enforcement leading to seizure and forfeiture of the house.

Without any particular basis, we will illustrate the uncertainty of this rental cost by expressing it as a range going from half to double the $66 per pound point estimate, but caution the reader that this range should be seen as a place holder to remind us of the imprecision in the calculations. It should not be construed as a confidence interval or as lower and upper bounds.

Rent for a Commercial Greenhouse Growing Operation

Besides economizing somewhat on electricity, the great appeal of greenhouse based growing is the lower rental cost. State agricultural extension services provide return-on-investment analyses for all sorts of farming, including greenhouse based farming. While there are some differences across studies, notably concerning heating costs which vary by region, it is clear that the rent or structure costs are much, much lower in greenhouses than they are in a typical residential house.[13]

Typical greenhouse construction costs are $5 - $12 per square foot[14]. Even factoring in equipment costs and using aggressive depreciation schedules, that still leaves amortized capital cost on the order of $2 to 3 per square foot. To give a particular example, the Ohio State University Extension (2008) provides budgets for hydroponic greenhouse operations for tomatoes and lettuce. Structure and environmental control equipment for a 12,288 square foot greenhouse each total about $50,000 for either crop; growing and delivery equipment costs are higher for lettuce than tomatoes (roughly $60,000 vs. $20,000), leading to somewhat higher amortized annual fixed costs for lettuce ($2.60 per square foot) than tomatoes ($1.97 per square foot).[15]

For a second example, consider Uva and Richards' (2000) estimates of average costs for greenhouses in New York State. The overall cost of $13.46 per square foot per year was dominated by labor ($3.87 per sq. ft. per year), plants, materials, etc. – all things we

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[13] One disadvantage of greenhouses is that they might be more vulnerable to being burglarized. Sellers of expensive illegal drugs (cocaine, heroin, etc.) are robbery targets because their drugs have high value per unit weight (akin to why electronics and jewelry make better theft targets than furniture) and the drug sellers cannot call the police. It is not clear how this would play out for greenhouse-produced marijuana post-legalization. If wholesale prices are in the range of $350 per pound, that is more valuable per unit weight than a laptop computer but less than a cell phone. It is also not clear whether greenhouse operators would feel free to call the police or whether greenhouse operators' property insurance policies would cover theft of marijuana. We ignore this issue of burglary risk in part because it is so hard to quantify and also because in the end we base our post-legalization cost estimate on production in houses, not greenhouses.

[14] This is for the modern double polyethylene style greenhouse. Classic glass-pane greenhouses are more expensive, on the order of $30 per square foot to build, and so are now less commonly built.

[15] Both figures are for total area of the greenhouse, amortizing at 20% per year. OSU (2008) assumes 90% space utilization so the costs per square foot utilized for plant growing are about 10% higher.

consider elsewhere. The components of amortized fixed costs were land rent ($0.08 per square foot per year), interest and depreciation on the structure ($0.90), property taxes ($0.14), insurance ($0.38), building repairs ($0.16), and lease/rental and repair costs on capital equipment ($0.40). Adjusting for inflation and rounding up, they total roughly $2.75 per square foot per year in current dollars.

One might worry that these studies understate land costs in California. (Land rent in the OSU calculations was only $240-300 per acre per year.) . However, even if the rental cost on land were $1,000 per acre per year (which is high for the state, but may be appropriate for some counties) and only 25% of that land could be used effectively for crop production, the land rental would still be less than $0.10 per square foot ($1000 / 25%) / 43,560 square feet per acre = $0.09 per square foot).

Given the assumptions above for greenhouse productivity of 0.1 pounds per square foot per harvest and two harvests per year, the $2 - $3 per square foot per year cost translates to $10-15 per pound.

2.4: Summary
Table 1 summarizes the considerations above concerning the production cost per pound of marijuana (specifically sinsemilla) for the three indoor production modalities.

Table 1: Estimated Post-Legalization Production Costs for Three Indoor Marijuana Production Methods

	5' x 5' indoor "hobbyist"	In a 1500 square foot residential house	1 acre 50% covered with greenhouses
Production Statistics			
Production Intensity (lbs/sq ft per yr)	0.42	0.42	0.21
Square feet cultivated	25	1300	21,780
Annual Production Rate (lbs)	10.5	546	4574
Cost per Pound Produced			
Materials (Exclusive of lighting)	$150	$50 - $150	$50 - $150
Lighting	$75	$75	$0 - $25
Labor Grow	In-kind Donation	$40	$10 - 25
Structure/Rent	In-kind Donation	$33 - $132	$10 - 15
Total cost per pound produced	$225 + In-kind	$200 - $400	$70 - $215

3. OUTDOOR CANNABIS PRODUCTION

3.1 Production Costs per Acre for (Challenging) Legal Crops[16]

This subsection aims to shed light on the cost of outdoor cannabis cultivation when all of the mechanization and technology of modern industrial agriculture can be brought to bear by considering production costs for legal agricultural products that might be deemed comparable in some sense. It is important to emphasize that these estimates would pertain to what might happen if production could proceed entirely above board, without concern about even federal law enforcement. It is not clear whether the Drug Enforcement Administration would or would not enforce federal marijuana laws against farmers operating so brazenly, even what they were doing was fully legal with respect to California state and local regulations.[17]

We picked as comparators cherry tomatoes, asparagus and leaf lettuce, all crops currently produced in California. Cherry tomatoes are similar to cannabis in that they are first grown as seedlings in a greenhouse and transplanted by hand into the field, resulting in a highly labor intensive production system. Commercial cannabis would likely be sprouted in a greenhouse similar to the tomato process to allow growers more control over the initial stages of growth (Molinar et al., 2005).

Asparagus may be relevant because commercial asparagus crowns are often grown in a greenhouse prior to being manually transplanted to the field. Asparagus and cannabis also have similar fertilizer inputs because both require a nitrogen rich soil environment (Graper and Burrows, 2001; Aegerter et al., 2007).

Leaf lettuce production is relevant because of the care required to harvest and transport the delicate crop. Similar care is taken to ensure that the crystallized buds from a cannabis plant are not compromised in the harvest (Tourte et al., 2009).

Our source of cost estimates is a series of studies produced by the University of California at Davis as a part of the Agricultural & Resource and Economics Outreach and Extension program since 2004. The program website provides PDF reports and in some cases detailed spreadsheet calculations for 153 agricultural cost studies. Each report

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[16] Carnegie Mellon Heinz College student Leigh Halverson did the initial analysis for this section.

[17] To clarify: None of the production cost estimates factor in "risks and prices" (Reuter and Kleiman, 1986) compensation for the effects of law enforcement. However, some might more readily believe that federal law enforcement could look the other way with respect to production done discreetly in a residential house, where the activity is invisible to passers-by, but have a harder time ignoring open farming visible to anyone driving down the road. Large scale green house operations present an intermediate case in terms of flagrancy/visibility; it is not obvious from the road what is being grown inside a greenhouse, but the presence of some sort of agricultural activity is unmistakable.

focuses on a specific agricultural facility in California providing a series of case studies for different fruit, vegetable, field, tree, vine crops and animal commodities.

The production costs estimated by the UC Davis studies varied from $5,600/acre for asparagus in the Imperial Valley to $18,500/acre for cherry tomatoes in the San Joaquin Valley, with lettuce falling in between ($6,400/acre in the Imperial Valley). The primary variable differentiating these estimates is labor costs. Cherry tomatoes are highly labor intensive because the seedlings are transplanted from the greenhouse and re-planted in the field by hand. Cherry tomatoes are also handpicked and sorted into three colors in the field later in the season.

It is not clear how labor intensive outdoor legal marijuana cultivation would be. Current production of cannabis is labor-intensive, but that may be because of some combination of (1) small operating scale thwarting mechanization (2) typical grey literature descriptions are of boutique quality, whereas farmed cannabis would be generic sinsemilla or even commercial grade, and (3) what Reuter (1983) terms "structural consequence of product illegality". Legalization may allow for technology innovations that will reduce labor as a percentage of total production costs. Nevertheless, to be conservative and in recognition of the fact that outdoor cannabis cultivation as practiced today often involves transplanting of seedlings, we proceed with the cherry tomato cost.

The UC Davis production cost estimates were based on fairly low rent land ($240 - $300 per acre per year). Although a proportionally small contributor to total cost of production for an expensive crop such as tomatoes, land costs are highly variable across the state of California. The rent in Shasta or Trinity County is more like $1,000 per acre per year (SOURCE). If production were legalized only in counties with such higher land values, that could increase somewhat the cost of legal marijuana production. So we round up from $18,500 to a total cost of $20,000 per acre per year.

3.2 Production Cost per Acre for Hemp[18]

Industrial hemp was widely grown legally in the past (e.g., for rope fiber) and is still grown legally in a number of countries, particularly China but also on much more limited basis in Canada (Fortenberry and Bennett, 2000). Logically, it ought to be an even better analog for estimating the cost of farming marijuana legally than are tomatoes, asparagus, or lettuce. Even though hemp and marijuana are different products, they harvested from the same species of plant.[19] The primary difference is potency; hemp varieties have lower THC content but more and longer fibers (Fortenberry and Bennett, 2004).

[18] Carnegie Mellon Heinz College student Andrea Meyer contributed to this and the following section.
[19] Cannabis is sometimes described as including three variants: Cannabis Indica, Cannabis Ruderalis, and Cannabis Sativa. Cannabis Indica and Cannabis Sativa can both produce marijuana, hashish, and hashish oil, but only Cannabis Sativa is used to produce hemp.

However, the quality of the industrial hemp production cost estimates we identified is weaker than those of the studies of more conventional crops described above. Fewer are done by professional agricultural economists, and even those that are (e.g., Cochran et al., 2000) are inherently more speculative because they cannot base their analysis on direct observation of contemporary production in the U.S. Apart from a brief period during World War II when availability of superior alternatives (e.g., jute) was interrupted, industrial hemp has not been widely grown in the U.S. since the late 19th and early 20th centuries, and professional assessments of its economic viability in the U.S. today are not encouraging (Cochran et al., 2000).[20]

With that caveat in mind, the industrial hemp literature suggests even lower estimates of production costs than derived above, so it reinforces the overall conclusion that farmed marijuana would have production costs per pound that are very, very low compared to current prices.

NORML's web site (http://norml.org/index.cfm?Group_ID=3395) lists 17 states that authorized studies of the economic feasibility of hemp production. Several studies include production cost budgets. Cochran et al. (2000) is a relatively late study in that group and appears to be aware of the earlier studies. Cochran et al. summarize the production cost estimates as ranging from $175 to $616 per acre. (Those costs are both per acre and per year since they presume one harvest per year.)

Cochran et al. (2000) suggest that the lower estimates may have omitted land and/or fixed costs. On the other hand, studies that provided separate estimates for both hemp and seed production costs tend to find lower costs for seed production. Arguably, hemp grown for seed is the better analogy because cannabis grown for seed is more widely spaced to allow for lateral growth of branches, whereas cannabis grown for fibers are crowded together to encourage length and height (Ehrensing, 1998). The production cost of cultivating for seed is lower because this spaciousness means the grower does not buy as much seed or have as many individual plants to tend.

However, this is a distinction without a difference. If, as we suggest below, farming yields 500+ pounds of usable dry cannabis per acre, any of these hemp-based production cost estimates suggest that legal, farmed cannabis production costs could be on the order of $1 per pound. When production costs get that low, the main driver of retail price will be things other than production costs (e.g., processing, marketing, and retailing costs).

There are many reasons to be skeptical of these industrial hemp studies. First, not all the studies referenced in Cochran et al. are conducted by experienced agricultural

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20 Fortenbery and Bennett (2004) review of the literature is slightly more positive, arguing that it could compete with row crops if not specialty crops, particularly if technological innovation in harvesting and processing reduced their labor intensiveness.

economists; it is possible that some people studying the economic feasibility of industrial hemp production may have an overt or subconscious incentive to find that production costs are low, to make the industry's potential look favorable. Indeed, the cited cost estimates are far below those the UC Davis study reports for conventional agricultural products. Nevertheless, to the extent that these studies have merit, they reinforce the notion that legally farmed cannabis could produce marijuana at very low prices. Indeed, they suggest that a figure of $20,000 per acre based on cherry tomatoes may be generous by more than an order of magnitude.

3.3 Production Yield per Acre

Precise figures on yields for outdoor cannabis cultivation are difficult to come by, but we believe yields of 2,000 – 3,000 pounds of dry cannabis material per acre per year can be anticipated, of which perhaps 575 pounds per acre per year would be bud as opposed to leaves and other lower quality material.

Our primary basis is an oft-cited and not infrequently criticized study by the Drug Enforcement Administration (US DEA, 1992). It describes marijuana growing experiments conducted by the University of Mississippi that used planting densities of 9 – 18 square feet per plant (high density) and 36 – 81 square feet per plant.

The grey literature's main criticism of the study seems to be that it concluded that yields were on the order of one pound per plant, a ratio that has entered into sentencing equivalency considerations. Yields of one pound per plant are almost an order of magnitude higher than figures in the literature for indoor production, such as Toonen's 1.2 ounces per plant per harvest based on indoor growing operations in the Netherlands.

The main explanation for the difference is that outdoor plants are spaced more widely and grown to much, much larger sizes. Indoor operations seek to maximize yield per square foot, which is done by planting densely and harvesting when plants are smaller (Bouchard, 2008).[21] Also, indoor operations can produce multiple harvests per year. Outdoor operations are confined to a single harvest per year (at least in temperate areas), so letting the plants grow bigger does not carry an opportunity cost in the form of delaying planting of the next round of plants.

Also, the DEA yields are for leaves and bud, not just bud. Bouchard's (2008) estimate of 1.9 ounces per plant grown outdoors pertains to just the buds. Leaves are shunned as "commercial grade" marijuana, but they do contain THC, and processing that bulk matter to concentrate the THC is simple and amenable to efficiencies when done at scale.

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[21] High yield per square foot is particularly important today, when avoiding detection by law enforcement is a paramount concern. It would remain important for house-based cultivation after legalization not only because of the risk of federal enforcement but also simply because of cost. The calculations above show that rental costs per square foot are more than a hundred times greater for a residential house than for a farm field.

One step we took to sort out this confusion in the literature was to interview four people involved in outdoor cultivation, one of whom was able to give an extremely detailed accounting of production operation, cost, and yield over the last eight growing seasons for, in a typical year, 80 plants grown on a 50' x 100' plot. Yield in that operation was even higher (2.5 pounds per plant, usable dry) because the plants were treated more like trees in a small orchard than a field of a low-maintenance crop.

It is also worth noting that the DEA believes its figure are conservative because they are based on "oven dried" weight, and oven drying results in greater weight loss relative to wet weight than the drying methods used in the cannabis industry.

Table 2 Plant spacings and yield from the nine DEA/University of Mississippi experiments (US DEA, 1992) and our subject

	Year	Yield per Plant	Pounds per plant	Square Ft. / Plant	Pounds/Acre
High Planting Density					
Univ. of MS	1985	222 grams	0.49	9	2,369
Univ. of MS	1986	274 grams	0.60	9	2,924
DEA	1990	233 grams	0.51	18	1,243
DEA	1991	215 grams	0.47	9	2,294
Low Planting Density					
DEA-A	1990	777 grams	1.71	81	921
DEA-B	1990	936 grams	2.06	81	1,110
DEA-C	1990	640 grams	1.41	81	759
DEA	1991	1015 grams	2.24	72	1,354
DEA	1991	860 grams	1.90	36	2,294
Our contact	2001-2009	1134 grams	2.5	62.5	1,742

Table 2 summarizes the yield information. We do not believe simply averaging all the rows in the table is the right way to estimate yield. A plant spacing leaving 81 square feet per plant is excessive because that leaves vacant space between adjacent plants. It should be thought of a spacing that lets the plants grow to essentially their maximum size with minimum interference from adjacent plants. Photos of our contact's planting spaced at 62.5 square feet per plant show abundant spacing, in that case necessitated by the hillside terrain.

Instead, we base our point estimates below on the data for 9 square feet per plant; the average yield for those three lines of the table is roughly 2,500 pounds per acre. Since there are 43,560 sq. ft. per acre, that suggests 4,840 plants per acre. Multiplying 4,840 plants per acre by Bouchard's 1.9 ounce of bud per plant suggests that 575 pounds of that would be bud, and the rest leaf and other matter.

The leaf and other matter may be of little value as a finished product, at least to users looking for high-quality marijuana. However, the leaves do contain THC, and we return below to some speculations about whether methods might be developed for extracting that THC economically. If the THC content per unit weight is even one-quarter in leaves what it is in the buds (e.g., 2.5% vs. 10% THC by weight), then the leaves and other materials would contain almost half (46%) of the total THC produced.[22]

There are some other points of reference in the literature, and these suggest that our estimates based (primarily) on the DEA study are if anything conservative. Leggett (2006, p.19) provides describes cannabis resin yields of 76 – 180 grams per square meter for outdoor production in Morocco, Mexico, and South Africa. That is equivalent to 700 – 1600 pounds per acre of resin. Leggett (2006) reports that it takes 20 – 100 grams of plant material to produce one gram of resin, a far greater compression factor than occurs with producing commercial grade marijuana (e.g., 4:1 from drying). McNeill (1992) reports yields of up to 2,000 kilograms per hectare (1,784 pounds per acre) from relatively low-tech farming in Morocco. Likewise, Cochran et al.'s (2000) assessment of the viability of industrial hemp production cites other sources that mention 5 tons of hemp being produced per acre and yields of seed alone of 1,000 pounds per acre.

3.4 Production Cost per Pound

Even if cannabis production is as costly as cherry tomato growing (~$20,000 per acre) the resulting cost per pound would be quite small, although the precise ratio depends on how one prorates the cost over production of the two distinct products: 575 pounds of buds and roughly 2000 pounds of other cannabis material.

The simplest cost would be to lump the two products together and report it as $20,000 / 2500 = $8 per pound of (mostly) commercial grade marijuana.

It is important to note that this figure is more of an upper bound than a best estimate. If production costs are more like those of lettuce or asparagus ($6,000 per acre), the cost per pound falls to $6,000 / 2500 = ~$2.50 per pound. If production costs were akin to those mentioned in the industrial hemp studies, then the implied price would fall below $1 per pound.

However, whether the cost is $1 per pound or $8 per pound or even $10 per pound, the key point is that the production cost would be an order of magnitude lower than the low

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[22] (2500 – 575) * 2.5% / [(2500 – 575) * 2.5% + 575 * 10%] = 46%. Cannabis quality from the user's perspective depends on more than just THC content, but we do not have information on whether the other psychoactive chemicals in cannabis are even more or not so much concentrated in buds as is the THC.

end of commercial grade prices per pound now seen in the U.S. Apparently, California-farmed legal commercial grade marijuana could outcompete commercial grade marijuana produced illegally in Mexico or in parts of the U.S. where production remains illegal.[23]

It is also interesting to think about a THC-equivalent price for marijuana whose potency is comparable to sinsemilla cultivated indoors. That is, even if outdoor cultivated marijuana buds generally had lower THC content the indoor cultivated buds, it is possible to concentrate THC extracted from other plant material that has lower THC content because resin is oil-soluble and denser than water; other leaf mater is water soluble and/or floats because it is lighter than water.

To illustrate the concept, suppose the 575 pounds of buds were 10% THC by weight and the remaining roughly 2,000 pounds were 2.5% THC by weight, and sinsemilla cultivated indoors is 15% THC by unit weight.[24] Then outdoor farming would be producing THC at a cost equivalent to producing sinsemilla for less than $30 per pound.[25] That is only about 1% of the current wholesale price. Gieringer (1994) also speculates that in the absence of taxation, the legal price of marijuana could fall by 99%.

THC-extraction would involve some cost and some loss of THC , and we have no way to estimate extraction efficiency or cost for industrial THC extraction. However, Cervantes (2006) describes a wide range of home-processing approaches, e.g., agitating leaves in a washing machine filled with ice water, supposedly yielding 3 kilograms of resin from 100 kilograms of leaf in one (14-hour) day of work.

The methods Cervantes describes are batch-based, but many would be amenable to continuous-flow operations if marijuana were legal and associated equipment would not attract enforcement attention or create a seizure risk. Such automation might greatly reduce labor effort, so we do not try to guess what it might become.

For the sake of argument, let us suppose that all of the farmed material were subject to a resin-extraction process with the efficiency Cervantes describes, and the resulting resin had a THC content comparable to indoor-cultivated sinsemilla. This is probably conservative because: (1) In Cervantes' example the input was all leaf, not leaf and bud,

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23 Domestic U.S. marijuana production focuses on high-grade types; most commercial grade marijuana is thought to be imported.

24 These are round numbers that are roughly consistent with University of Mississippi (20XX) potency data. They list sinsemilla buds' potency as 10.81%, which is presumably an amalgam of indoor and outdoor grown buds. The 2.5% THC content for leaves is what the University of Mississippi reports for "marijuana" leaves; for the small number of "sinsemilla loose leaf" observations they report a higher average potency of 4.12%, so using 2.5% may be conservative.

25 At the assumed THC contents, 575 * 10% + 1925 * 2.5% = 105.6 pounds of THC, which is the amount of THC in 105.6 / 15% = 704 pounds of sinsemilla that is 15% THC. $20,000 production cost / 704 pounds = $28.40 per pound.

(2) resin often has higher content than sinsemilla, and (3) mechanization and continuous processing might well produce higher conversion rates as well as labor savings.

Even with these conservative assumption, $8 per pound farmed material converted into resin at a 100:3 ratio would imply costs of $265 per pound for material that had the THC content of indoor-cultivated sinsemilla, ignoring capital and labor costs of the processing. This at the low end of the indoor sinsemilla production cost estimates derived above. Of course if the farming costs were lower, akin to lettuce or asparagus not cherry tomatoes, the corresponding cost of this material would also be lower, below $100 per pound.

Hence, it is entirely possible that if marijuana production were truly legal in all respects, then farm-based THC-equivalent products might outcompete indoor production on a THC-equivalent basis.

4. COSTS FOR PROCESSING LEGAL CANNABIS

Cannabis is not sold in raw form; it needs to be processed before use. We take two approaches to estimating the cost of processing legal cannabis. The first is to take current sinsemilla processing methods under an illegal framework, adjust for plausible efficiency improvements, and substitute wage rates typical of legal agricultural product processing. The second is to use legal tobacco processing as a proxy for legal cannabis processing costs. Plausibly the first is more relevant for sinsemilla, whereas the second may only be informative for commercial grade marijuana processing.

4.1 Current Costs of Processing Sinsemilla[26]

It is clear that labor dominates the cost of processing sinsemilla. The materials costs are relatively minor. We tried but failed to locate good, citable estimates on the total labor effort needed to process sinsemilla today. Calls to various materials providers seemed to provide estimates that centered around seven hours per pound, but we were unable to establish the provenance or reliability of such an estimate. The figure does not seem implausible if, as appears to be conventional wisdom, the “manicuring” stage is the most labor intensive step, since we have at least bits of information about labor intensity of that step.

It is perhaps useful to distinguish three general processing stages: harvesting, manicuring, and drying/curing.

Harvesting by hand is somewhat labor intensive, involving a number of steps (typically these include trimming the plant near its base, hanging it upside down to allow the plant to dry, trimming larger leaves, etc.). It seems plausible that this could be mechanized if

[26] Carnegie Mellon Heinz College student Alex Brant contributed original research to this section.

the marijuana were grown in farm fields, but might not change substantially for legal indoor growing.

For sinsemilla, the subsequent step of "manicuring" (trimming smaller leaves from the cannabis buds) may be the most labor intensive step. This is now done with any of three levels of technology: manually with scissors, manually with an automatic trimmer, or mechanically. According to Cervantes (2006), who provides many photos of this and other processing stages, it takes four to six hours per pound of cannabis with scissors vs. one to two hours with an automatic trimmer.

Processing speeds for mechanical trimmers are unknown; promotional claims mention five to ten pounds per hour for machines such as "The Twister" (www.trimscene.com). Two feasible ways to improve understanding would be (1) collecting field observation data on processing rates with current machines and (2) engaging mechanical and food processing engineers to judge what would be possible with a serious development investment by professional engineers, as opposed to the home workbench design and fabrication technology embodied in something like "The Twister". Time and resource limitations precluded our taking either step. We somewhat arbitrarily assume that the current processing rate is one pound per hour, to allow for exaggerated marketing claims, multiple operators, and/or secondary trim by hand. However, we guess that three to five pounds per hour may be possible after legalization, on the assumption that legitimate engineering firms would be willing to design and manufacture machines for a legitimate industry. Implications of these arbitrary assumptions are discussed below.[27]

The final steps are drying and curing the cannabis. Drying can be accelerated with various techniques, but in the illegal industry still typically takes days; curing takes a few days to weeks. These are not inherently labor intensive steps, but for small-scale operations create inconvenience ("set up charges") because they are done in batch mode with small batches. These steps seem amenable to substantial economies of scale if processing were done at an industrial scale post-legalization.

Table 3 attempts to combine these various bits of information. It admittedly rests on a far less scientific and empirical basis than is desirable in serious policy analysis. Table 3 only considers the labor costs of processing, but our sense is that uncertainty about those costs swamps plausible ranges of other costs of processing (e.g., materials costs), so we do not attempt to estimate those non-labor processing costs explicitly.

Table 3: Speculations About the Labor Intensity and Associated Costs of Processing Marijuana Currently and After Legalization

	Currently (While Illegal)	After Legalization

[27] Machines like the Twister are not cheap at $14,500. However, if an operation producing 500 pounds per year amortized that investment over 4 or 5 growing seasons, the amortized cost per pound falls below $10.

	Scissors	Electric Trimmers	Machines (e.g., "Twister"	Low End	High End
Labor Intensity (Hours per pound)					
Harvesting	1.5	1.5	1.5	1.5	1.5
Manicuring	5	1.5	1	0.2	1/3
Drying/Curing	1.5	1.5	1.5	0.5	1.5
Total Hours per pound	8	4.5	4	2.2	3 1/3
Wage rate	$20 – 25 per hour			$$10 per hour	
Conjectured total cost	$80 - $200 per pound			~$20 - $35 per pound	

4.2 Tobacco Processing Costs[28]

One might think tobacco could be a reasonable proxy for large scale commercial legal cannabis processing because tobacco is dried, cut, and in most cases rolled into cigarettes before being sold to consumers. If production of legal cannabis could operate on a similar business mode, it appears that processing cost could be nearly an order of magnitude below those just estimated, perhaps closer to $3 per pound.

The US Growers Tobacco Company (USGTC, 2010) site has a calculator that estimates the processing costs (receiving, grading, stemming and drying green tobacco) as $0.30 per pound of green tobacco and estimated after sale charges (storage, insurance, transportation, and agent commission) of $0.17 per pound of dry tobacco. Tobacco, like marijuana, loses weight when dried, but less dramatically. Conversion factors vary slightly by type of tobacco, but roughly one pound of wet, green tobacco leaves is the equivalent of 0.60 pounds of dry, cured tobacco ready for sale. So the total cost of processing green/wet tobacco is $0.58 per pound ($0.30 + $0.17/0.6).

In the case of cannabis, 4-5 pounds of wet cannabis equals one pound of processed product (US DEA, 1992; Cervantes, 2006). So if the cost per pound of pre-processed material remained at $0.58 per pound, the processing cost per unit of processed marijuana would be $2 - $3 per pound.[29] That figure is only one-tenth of Table 3's estimate based on minor modifications to current methods. So if tobacco processing were a reasonable analog – which it very well might not be – then the efficiencies of industrial operations might cut processing costs by another 90% above and beyond the 60-90% cost reduction Table 3 envisions from modest automation coupled with not having to pay labor a premium for participating in an illegal activity.

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[28] Research for this section was done by Carnegie Mellon Heinz College student Leigh Halverson.

[29] Arguably the true comparable is more like $1.50 - $2.00 per pound because storage, insurance, and shipping are not included in Table 3's estimates.

4.3 Inspection and Regulatory Costs
The Proposition does not describe or create a regulatory framework for marijuana production; it would merely empower local governments to do so. Hence, it is very difficult to guess how if at all compliance with regulatory requirements might increase processing or cultivation costs.

The only data points of any kind we have on this are due to Dale Gieringer (2010), the director of California NORML, who observes that: (1) regulatory oversight of the Dutch medical marijuana producer Bedrocan (http://www.bedrocan.nl/english/home.html) is so stringent that its prices are higher than those in Dutch cannabis shops and (2) marijuana potency and contamination testing can be done for $100 per sample.

The cost burden of such testing and inspection demands enormously on how large a sample can be tested at once. If every ounce had to be tested individually, the cost burden at Gieringer's suggested rate would obviously be $100 per ounce. If a house-based operation producing 546 pounds per year in four equal size harvested could somehow have an entire quarter's harvest tested at once, the cost would fall below $0.05 an ounce.

This is an essentially nihilistic range, so we prefer to think of the estimates here is those that would pertain if inspection and compliance costs were merely akin to those of existing agricultural products, which is to say negligible relative to costs in the hundreds of dollars per pound.

5. SUMMARY

Before recapping numbers estimated above, it is worth stating again that this was an extraordinarily speculative undertaking. Hard data are scarce; hard data reported in refereed scientific journals are all but non-existent. This paper is simply the product of a good faith effort to cobble together bits of information floating in the grey literature. As such it is subject to greater uncertainty and error than is the norm, even in the inexact science of policy analysis.

That said, it seems clear that production costs after-legalization would be well below current prices. Indeed, it is appears that even today, despite all the inefficiencies and extra costs generated by prohibition, production costs may be well below current prices. One explanation for that might be that illegality generates high accounting profits even in steady state as compensation for the various risks of undertaking an illegal activity (c.f., Reuter and Kleiman, 1986; Caulkins and Reuter, 2010). Another is that current marijuana prices are not sustainable, and nontrivial declines in marijuana prices may occur even if legalization does not pass in California.[30]

We attempted to estimate production and processing costs on a range of bases and for various production modalities. It is hard to say which is most relevant because no one knows how legalization will play out in California even if the proposition passes.

At one extreme, perhaps no local jurisdiction in California will allow commercial production – e.g., because the federal government threatens to withhold federal funding from any jurisdiction that does so. In that case only the non-commercial growing in a 5' x 5' area is pertinent. The estimated cost of that is $225 per pound for a successful, well-managed operation, plus in-kind contribution of labor and forgone living space. A well-managed operation of that scale could produce roughly 10 pounds per year, enough for almost 50 people at an average annual consumption rate of 100 grams per year (Kilmer and Pacula, 2009). Since $225/pound is less than one-tenth the current wholesale price of high grade marijuana (Narcotic News, 2010), even that very limited form of legalization might exert substantial downward pressure on prices if an important segment of the market uses home-grown marijuana. Indeed, a principal advantage of allowing home-grown marijuana is to siphon demand away from illegal providers.

It is not clear whether much truly commercial production would be pursued under the guise of grow one's own. On the one hand, someone producing 10 pounds per year would have surplus they could sell. On the other hand, it might be easier to obtain a medical marijuana producers permit and be free of the 5' x 5' space restriction. Perhaps the most likely scenario is that at least one jurisdiction within California would allow commercial production. And perhaps the most likely federal response would be to prevent brazen open-air farming or large greenhouse-based operations, but not to exert much effort rooting out production done discretely in private homes. This is fairly similar to what is happening in South Australia (Sutton and McMillan, 2000SOURCE)

In such circumstances we would estimate production costs for sinsemilla of $200 - $400 per pound, plus another $20 - $35 per pound for harvesting and processing. Such costs are roughly comparable to current prices per *ounce*, and are about a factor of ten lower than the current pound price for sinsemilla in the U.S. [31]

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[30] There are already media reports of sharp price declines, e.g., a May 15, 2010 National Public Radio report (available at http://www.npr.org/templates/story/story.php?storyId=126806429) which describes "hard times" in California's traditional marijuana growing regions.

[31] As Appendix C reports, ounce prices for sinsemilla in California are typically on the order of $350 - $400, and Narcotics News (2010) cites $3,000 - 4,500 per pound as a price for "high grade" marijuana in San Francisco. http://www.narcoticnews.com/Marijuana-Prices-in-the-U.S.A.php, accessed March 3, 2010.

One factor that might soften the price decline would be highly burdensome regulatory, testing, inspection, and reporting requirements. Likewise, if a $50 per ounce ($800 per pound) tax were collected, the tax would represent roughly two-thirds of the taxed purchase price for bulk sinsemilla. (Sinsemilla sold in small quantities, particularly in a service establishment such as a marijuana café where sales might have to cover overhead, wait staff salary, etc. might be considerably more expensive per unit weight, so the tax's proportion of the taxed cost would be correspondingly smaller.)

As Bond and Caulkins (2010) note, given current estimates of the cost of smuggling marijuana illegally in the U.S., production costs that low might allow California grown sinsemilla to dominate the U.S. sinsemilla market even with a $800 per pound tax. This has three implications. First, if California can collect excise taxes on marijuana bound for export to the rest of the U.S., taxes on such exports could be a much larger source of revenue than would be taxes on sales for consumption within California. Second, regardless of whether California manages to collect the excise taxes, marijuana legalization in California might depress marijuana prices throughout the lower 48 states. Third, such exports and downward pressure on prices outside of California might attract a response from the federal government.

The conclusions so far have presumed greenhouse based production would remain infeasible. If it were possible to produce marijuana in large-scale greenhouse operations, production prices could fall still further. In one respect this does not matter. Whether sinsemilla production costs are $300 per pound indoor or $150 per pound in a greenhouse or even the $30 per pound figure from one of our various outdoor farming based estimates, (1) those values are so low relative to current prices as to extend beyond where price effects on consumption can reliably be extrapolated from current data and (2) final prices may be driven more by the costs of marketing, branding, bundling, and retailing than by production, just as the production costs (typically in China) of many household goods are a modest proportion of their retail prices.

In another respect, allowing greenhouse-based production could matter. The increased natural operating scale might lead to fewer suppliers, making regulation easier. In Table 1 above, we speculated that a one-acre greenhouse operation might produce roughly ten times as much per year as would indoor production in a typical residential house. And there is nothing magical about a one-acre greenhouse operation. If the typical greenhouse farm covered 10 acres, and such farms were able to outcompete indoor production in houses, the number of producers could be a small, small fraction of the number of producers if greenhouse based growing were not allowed.

This might create an interesting tradeoff. Legalizing greenhouse-based operations, while continuing to prohibit indoor production beyond a 5' x 5' personal plot, might leave a much more concentrated industry that is easier to regulate and possibly to tax.

6. CODA: INSIGHTS CONCERNING ENVIRONMENTAL EFFECTS OF MARIJUANA LEGALIZATION

The marijuana legalization debate is dominated by considerations such as rights and liberties, budgetary considerations, and effects on use, particularly by youth. However, at various times environmental considerations are raised. For example, illegal cultivation in national parks and forests creates a certain amount of environmental damage that might be eliminated if legalization shifted cultivation to land owned by the marijuana producer, because land owners have incentives to look after the long term fertility of those lands. As a byproduct of investigating production processes and technologies we obtained some insight into the scale of some of these issues.

The overall finding is that environmental issues are relatively minor considerations. The reason, ultimately, is that even heavy marijuana users do not use quantities that are large compared to the quantities of other agricultural products. A reasonable rule of thumb is that the quantity of marijuana consumed in a country or region is 100 grams per past-year user (Bouchard, 2008; Kilmer & Pacula, 2009, UNODC, 2009). That is less than the weight of a single medium-sized apple.

To be fair, the marijuana is dried. Wet weight is 4-5 times dry weight, so annual consumption per past-year marijuana user on a wet weight basis is more like 400 – 500 grams, or essentially one pound of agricultural product per person per year. By comparison, Americans consume roughly 100 pounds of fresh fruit (of all kinds) per person per year, and the equivalent of an additional 180 pounds per year in processed forms (U.S. Apple Association, 2005).

Water consumption calculations give a sense of perspective. Cannabis is not a water intensive crop, but indoor cultivation requires attention to hydration levels, and Cervantes estimates that 16 plants will require between 10 to 25 gallons of water per week (Cervantes, 2006). Assuming plants are grown for 90-days before harvest, that is equivalent to 8 - 20 gallons of water per plant.

Toonen et al. (2006) find average yields of 1.2 ounces (33 grams) per plant per harvest, suggesting that indoor marijuana production requires about 0.24 - 0.61 gallons of water per gram of marijuana produced. At an average annual consumption of 100 grams, that is 24 – 61 gallons, or about the equivalent of flushing a standard toilet between once every month or two; clearly water consumption (at least for indoor marijuana growing) is simply not a concern.

Likewise, total area needed for marijuana production is not that large. Making precise statements is complicated by the lack of agreement in the literature about the total quantity of marijuana consumed in the U.S., either now or after legalization. In the next few paragraphs we will use 5,000 metric tons because it is a round number that is consistent with most current consumption estimates.[32]

With an outdoor production yield of 2,500 pounds per acre (1,134 kgs/acre), 4,400 acres of crop land would be needed to serve a 5,000 metric ton U.S. market. The U.S. has 922 million acres of farmland of which a little over 300 million is harvested each year,[33] so marijuana cultivation would only require 0.0014% of harvested cropland.

Of course, outdoor farming is probably not the most likely outcome. Suppose all of the 5,000 metric tons were provided by indoor growing with a yield of 546 pounds per house. Such domestic production would require about 20,000 houses (or less since the indoor production would mostly be sinsemilla, whereas most of the 5,000 metric tons would be commercial grade). 20,000 houses is a lot of houses, but there are about 75 million owner-occupied houses in the U.S., so 20,000 is just 0.027% of the total; widespread indoor marijuana cultivation would not exacerbate homelessness or solve the hang-over from the recent housing crisis. Indeed, a recent news article reported that there were 200,000 vacant homes in the U.S. just among those that had been constructed recently.[34]

It is harder to speculate about possible spill-over effects on Mexico, if California-based production induced crop substitution there, but these calculations suggest that environmental considerations would be a relatively minor factor in an analysis of the social-welfare effects of marijuana legalization.

References

Aegerter, Brenna, Karen M. Klonsky, and Richard L. De Moura (2007). *Sample Costs to Establish and Produce Asparagus.* San Joaquin Valley North: University of California Cooperative Extension. Available at http://coststudies.ucdavis.edu/files/asparagusvn2007.pdf.

Bouchard, M. (2008). Towards a realistic method to estimate cannabis production in industrialized countries. *Contemporary Drug Problems*, 35(2/3): 291-320.

Bouchard, M., Nguyen, H. (Forthcoming). Professional or amateurs? Revisiting the notion of professional crime in the context of cannabis cultivation. In T. Decorte, G.

[32] Gettman's (2007) is the only one that is much larger, at 9,830 metric tons. 5000 metric tons is probably substantially larger than post-legalization, indoor production because that production would be almost all sinsemilla quality, whereas currently the majority of consumption is of lower commercial grade. So 5,000 metric tons of sinsemilla grade would more than triple US THC consumption

[33] http://www.ers.usda.gov/StateFacts/US.htm

[34] http://www.bloomberg.com/apps/news?pid=20601109&sid=au67GKPyS_Dg

Potter, and M. Bouchard (Eds). *World Wide Weed: Global Trends in Cannabis Cultivation and its Control*. London: Ashgate.

Caulkins, Jonathan P. and Peter Reuter (forthcoming). How Drug Enforcement Affects Drug Prices. In *Crime and Justice –A Review of Research, vol. 39*, ed. Michael Tonry. University of Chicago Press.

Cervantes, Jorge. *Marijuana Horticulture: The Indoor/Outdoor Medical Grower's Bible*. Singapore: Van Patten, 2006. Print.

Cochran, Mark J., Tony E. Windham, and Billy Moore (2000). Feasibility of Industrial Hemp Production in Arkansas.

Edwards, Logan. *Gro Great Marijuana: An Uncomplicated Guide to Growing the World's Finest Cannabis*. Los Angeles: Sweetleaf, 2006.

Ehrensing, Daryl T. (1998). Feasibility of Industrial Hemp Production in the United States Pacific Northwest. Oregon State University, Station Bulletin 681, May. Available at http://extension.oregonstate.edu/catalog/html/sb/sb681/.

Fortenbery, T. Randall and Michael Bennett (2004). Opportunities for Commercial Hemp Production. Applied Economics Perspectives and Policy. 26(1):97-117.

Gieringer, Dale (1994). Economics of Cannabis Legalization. *Hemp Today*, pp. 311-324. Available at http://www.canorml.org/background/mjeconomics.html.

Gieringer, Dale (2010). Personal correspondence (May 28th, 2010).

Graper, David F. and Rhoda Burrows (2001). *Growing Asparagus.* South Dakota State University Horticulture, Forestry, Landscape and Parks Department. Downloaded from http://agbiopubs.sdstate.edu/articles/ExEx6009.pdf.

Kentucky Department of Agriculture News. (2010, January 15). *US Growers Tobacco Company creates new marketing opportunity* . Retrieved February 21, 2010, from Kentuky Ag News: http://www.kyagr.com/pr/kanonline/January152010/usgtc.htm

Kilmer, B. & R. Pacula. (2009). Estimating the size of the global drug market: A demand-side approach. TR-711. Santa Monica: RAND.

McNeill, T.R. (1992). Kif in the Rif: A Historical and Ecological Perspective on Marijuana, Markets, and Manure in Northern Morocco. Mountain *Research and Development*, 12(4):389-392.

Moeller, Kim (2010). An Analysis of Costs and Profits in Two Copenhagen Cannabis Markets. Paper presented at the 4th annual conference of the International Society for the Study of Drug Policy, Santa Monica, CA, March, 2010.

Molinar, Richard H., Michael Yang, Karen M. Klonsky (2005). *Sample Costs to Produce Cherry Tomatoes.* Fresno, CA: University of California Cooperative Extension. Available from http://coststudies.ucdavis.edu/files/tomatochsjv2004.pdf.

Narcotics News (2010). Website accessed March 3, 2010. http://narcoticnews.com/Marijuana-Prices-in-the-U.S.A.php.

National Drug Intelligence Center. (2009, July). *Cannabis Cultivation on Public Lands*. Retrieved January 2010, from National Drug Intelligence Center: http://www.justice.gov/ndic/pubs37/37035/public.htm#Top

O*NET. (2009, December 31). *O*NET Online*. Retrieved February 9, 2010, from O*NET: http://online.onetcenter.org/link/summary/11-9011.01

Reuter, Peter. *"Disorganized Crime: The Economics of the Visible Hand."* Cambridge, MA: MIT Press, 1983.

Reuter, Peter."The (Continued) Vitality of Mythical Numbers," *The Public Interest*, (1984), 75:135-147.

Reuter, Peter and Mark Kleiman "Risks and Prices: An Economic Analysis of Drug Enforcement" in Morris and Tonry (eds.) *Crime and Justice: An Annual Review of Research* Volume 7, 1986, pp.289-340.

Toonen, M. R. (2006). Yield of illicit indoor cannabis cultivation in the Netherlands. *Journal of Forensic Science*, 1050-1054.

Trim Scene Solutions Inc. Web. 24 Feb. 2010. <http://trimscene.com/>.

Solutions, T. (2010, February 7). n/a. (A. Brant, Interviewer)

Semuels, A. (2009, November 1). *Marijuana growers upend hard-luck California town.* Retrieved January 2010, from Los Angeles Times: http://articles.latimes.com/2009/nov/01/business/fi-dope-county1.

Sutton, Adam and Elizabeth McMillan (2000). Criminal justice perspectives on South Australia's Cannabis Expiation Notice procedures. *Drug and Alcohol Review*, 19(3):281-286.

Criminal justice perspectives on South Australia's Cannabis Expiation Notice procedures Adam Sutton, Elizabeth McMilla

Tourte, Laura. Richard F. Smith, Karen M. Klonsky, and Richard L. De Moura (2009). *Sample Costs to Produce Organic Leaf Lettuce.* Santa Cruz & Monterey Counties: University of California Cooperative Extension. Available at http://coststudies.ucdavis.edu/files/lettuceleaforganicсс09.pdf.

US Energy Information Administration (2009, October 31). *Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State*. Retrieved February 2, 2010, from Electric Power Monthly: http://www.eia.doe.gov/cneaf/electricity/epm/table5_6_a.html

US Growers Tobacco Company (USGTC). (2010). *Tobacco Owners Calculator*. Retrieved February 21, 2010, from US Growers Tobacco: http://www.usgrowerstobacco.com/USGTCCalc.htm

UC Davis Agricultural & Resource Economics. (2010). *Current Cost and Return Studies*. Retrieved February 21, 2010, from http://coststudies.ucdavis.edu/current.php

U.S. Apple Association. (2005) Total Apple Consumption Hits Record Levels in 2004. *Apple News*, 36(4):1-4.

United States Drug Enforcement Administration (US DEA). 1992. Cannabis Yields. Washington, DC: Department of Justice.